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RESEARCH ARTICLE

Process Modeling and Simulation of Ammonia Production from Natural Gas: Control and Response Analysis

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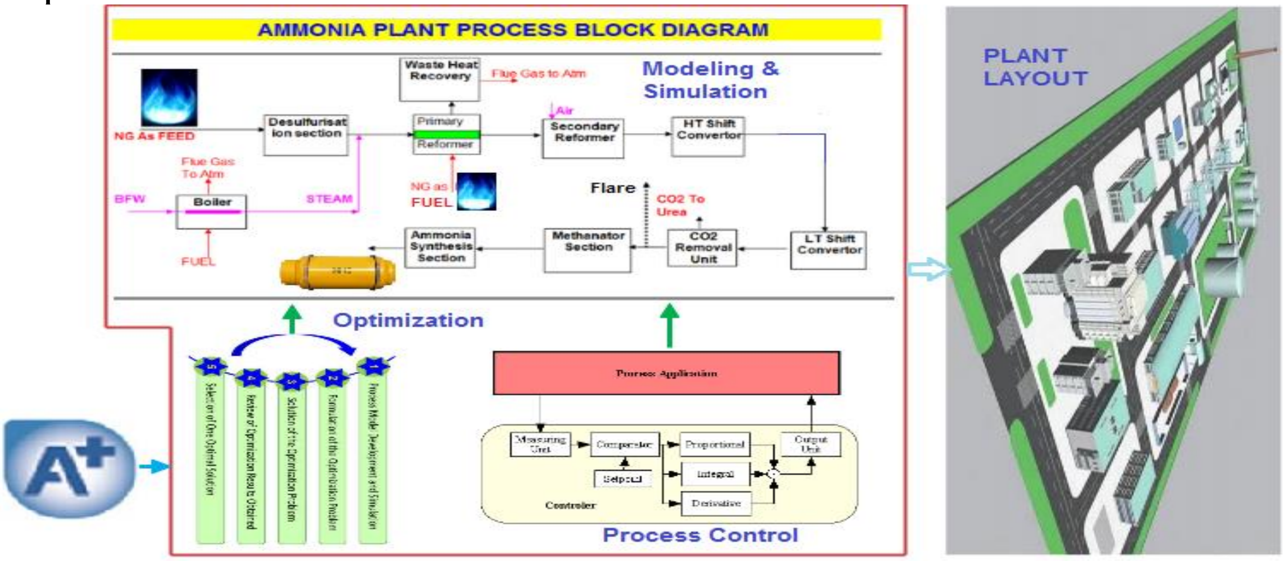
Abstract

Optimal production of ammonia (NH_3) using natural gas is necessary in order to make it available for wide range of applications including the manufacture of fertilizers, fuel for transportation and during synthesis of some chemicals. Achieving this would require strategic implementation of a control scheme to simulated ammonia production, capable of ensuring adequate realization of production targets. The work involves ASPEN Plus modeling, simulation, sensitivity analysis and control of NH_3 production process. Steam/carbon ratio, conversion of CH_4, removal of carbon dioxide (CO_2) and carbon monoxide (CO), hydrogen/nitrogen ratio and heat exchanger and separator temperatures were identified as requiring control in units any of these specifically impacts. As a result, approximately 176 tons of NH_3 was realized daily based on the simulation results and can be scaled-up using a calculated factor equivalent to 1.1375 to 200 tons/day capacity, in this design. Sensitivity analysis resulting in control of certain unit parameters is effective in ensuring process safety, maximum yield of important end-products and reduction in the cost of operation.

Keywords: Ammonia plant; Aspen Plus; Simulation; Process control; Natural gas; Sensitivity analysis; Modeling and optimization; Plant layout

Graphical Abstract



Introduction

Principal source of ammonia (NH_3) manufacture are hydrogen (H_2) and nitrogen (N_2) gas, following a natural or synthetic approach that are described as a complex heterogeneous catalytic or enzymatic process (Rouwenhorst et al., 2021; Tripodi et al., 2018). Roughly, half of the H_2 synthesized in industries (out of 60 million tons) and about 100 MMT of atmospheric N_2 every year, are extracted to produce NH_3 (Baltrusaitis, 2017; Philibert, 2017; Yilmaz & Ozturk, 2022). Liquefaction of NH_3 takes place by cooling the gas to -33°C at 1atm or rising the pressure to ≅10 bar at room temperature (Macfarlane et al., 2020; Stiewe et al., 2022). Major stages of production are steam methane reforming (SMR) of natural gas, water-gas shift reaction, and the Haber-Bosch process or simply grouped into the reforming and synthesis processes (Isah et al., 2019; Liu et al., 2020). While methods of NH_3 production as regards the feedstock used are divided into steam reforming from natural gas or other light hydrocarbons (e.g. naphtha and natural gas liquids), partial oxidation of heavy oil or waste oil, coal gasification and biological means using manure and organic wastes in the presence of microbes (Liu et al., 2020; Morgan, 2013; Partridge, 1976; Tavares et al., 2013; Zamfirescu & Dincer, 2008). Worldwide, 70-80% of NH_3 recovery is from natural gas by steam reforming, 22-30% using coal, 4% fuel oil and 1% naphtha (Bicer, et al., 2017a; Bicer, et al., 2017b; Brohi, 2014; Liu et al., 2020; Tavares et al., 2013). There exists, over 847 billion metric tonnes of proven coal reserve globally, the biggest being in the United States, Russia, China and India (Anantharaman et al., 2012; Burt, 1954; Liu et al., 2020; Pattabathula & Richardson, 2016). Ammonia is a high-purity source of carbon dioxide (CO_2) emissions and ≅ 1% of world's greenhouse gas emissions (Arora et al., 2018; Macfarlane et al., 2020). Morgan (2013) reported that, for 1 metric ton of NH_3 synthesized, 2.7 metric tons and 3.4 metric tons of greenhouse gas CO_2 is released from natural gas and coal respectively.

Areas of application of NH_3 are in explosives, wood and metal surface treatment plants, cosmetic plants, in paper, fertilizer and leather processing industries, as transportation fuel (e.g. during World War II) and in manufacturing plants like electronics, latex, paints, synthetic fibers and rubber, which makes it the second most manufactured chemical globally after sulphuric acid (Brohi, 2014; Ghavam et al., 2021; Liu et al., 2020; Oberauskas et al., 2020). Among the listed, 88% of NH_3 produced world over (of the 170 MMT annual output) goes to nitrogen fertilizer production, serving almost half of the world's food production (Chisalita et al., 2020; Gencer et al., 2022; Heidlage et al., 2017; Klerke et al., 2008; Liu et al., 2020; Macfarlane et al., 2020; Pattabathula & Richardson, 2016; Swearer et al., 2019). Gencer et al. (2022) reported that only 2 fertilizer plants in Nigeria and 1, both in Zimbabwe and Madagascar (making 4), out of a total of 16 in Sub-Saharan Africa (SSA), is in operation at the moment. At the moment, NH_3 utilization as fuel for electricity generation, heavy vehicle transport and energy storage are under development, because the chemical can go into gas turbines and internal combustion engines (Bartels & Pate, 2008; Bicer & Dincer, 2018; Macfarlane et al., 2020; Morlanes et al., 2020). Both NH_3 and H_2 are carbon free fuel alternatives; where Germany (where it began in 2018), Japan, China and Korea are actively planning the production of millions of fuel cell (Bartels & Pate, 2008; Calloway et al., 2019). Moreover, green ammonia is a term for NH_3 produced with zero carbon footprint which can be synthesized by electrolysis (Arora et al., 2018; Murai et al., 2022; Rouwenhorst et al., 2021; Swearer et al., 2019; Ye et al., 2017). According to level of CO_2 emitted, green ammonia production ensures 99.9% pure NH_3, blue ammonia ensures 90% while brown production (or the Haber-Bosch process) ensures that less than 90% of the gas volume is produced (Arrarte, 2022; Del Pozo & Cloete, 2022; Gezerman, 2022; Smart, 2022). Apart from a very high auto-ignition temperature (651 °C), high NOx emission, low flame speed, toxicity, narrow flammability limits (16-25% by volume in air) and high heat of vaporization that characterized NH_3 combustion which can be solved by working with somewhat oxygen (O_2) lean conditions and mixing with methanol, H_2 and gasoline, it is still better compared to H_2 (Brohi, 2014; Morlanes et al., 2020; Murai et al., 2022).

For SMR method utilizing natural gas to produce NH_3, if gas prices rise steeply, production cost sharply increase (Kelley et al., 2021; Kermeli et al., 2017; Khan & Kabir, 1995; Schnitkey, 2016). Specifically, natural gas is linked to 70-90% of NH_3 synthesis cost (Zamfirescu, et al., 2017; Huang, 2007). For instance, the world witnessed a decrease in natural gas prices between 2012-2016 due to increase in the gas production in the United States and since September 2021, Europe's natural gas costs are at record-high (Ghavam et al., 2021; Schnitkey, 2011; Stiewe et al., 2022). This would limit the purchasing power of users, especially the United States that accounts for 35-40% of world trade currently, being the largest importer (Zamfirescu, et al., 2017). The end-product or NH_3 can be stored and transported in huge cyrotanks onboard of ships, through mild steel pipelines and/or converting natural gas pipelines to transport it, as it is less costly to transport than H_2 in pipelines (Bartels & Pate, 2008; Zamfirescu, et al., 2017; Stiewe et al., 2022). An NH_3 pipeline built from the Gulf of Mexico to Minnesota which branches to Ohio and Texas is an example (Zamfirescu, et al., 2017). Storage of the gas is influenced by tank size, as 50000 tons NH_3 volume is stored at 33°C and 1 bar in large insulated tanks while amount around 1500 tons is stored under pressure in small stainless steel spherical tanks (Klerke et al., 2008).

However, before storage and transport, NH_3 is manufactured in process industries. In most cases, modeling, simulation, control, optimization, instrumentation and layout are designed (Demirhan et al., 2018; Singh & Saraf, 1981).

Modeling, simulation, optimization and control can be done on particular units or whole NH_3 process units (Araujo & Skogestad, 2008; Mahmoodi & Darvishi, 2017; Reddy & Husain, 1982). Process control had been used to improve plant capacity from 750-850 tpd (Araujo & Skogestad, 2008; Frahm et al., 2001; Mulholland, 1986; Shah, 1967). Commonly, refurbishment, replacement and redesign of an NH_3 plant helps in improving its capacity, efficiency and reliability (Dark & Stallworthy, 1985; Gupta & Borserio, 2004; Sanchez & Martin, 2018). Because energy, process risk, human failure and maintenance cost are two proven symptoms of NH_3 plant shutdown (Delboy et al., 1991; Eng & Gluckie, 2009; Kermeli et al., 2017; Williams, 1978; Williams et al., 1988). It is worthy of note that, implementing control strategies in NH_3 plants could sometimes be challenging (Funk, 1998). Specific objectives of the work are to specify natural gas grade which will go into a designed ASPEN Plus simulation of an NH_3 production plant, identify manipulated variables in need of control to keep prime units or conditions at desired set points by embedding a control scheme to the process design, carryout sensitivity analysis in order to optimize certain operating/unit/stream conditions and to determine the arrangement of different facilities within the processing area that minimizes construction cost and accidents.

Literature Review

Fritz Haber and Carl Bosch developed the Haber-Bosch NH_3 synthesis process in 1913 at Baden Aniline and Soda Factory (BASF) in Oppau, Ludwigshafen (Bartels & Pate, 2008; Brightling, 2018; Rouwenhorst et al., 2021; Smith et al., 2020). The exothermic process is facilitated by iron oxide catalyst at optimal temperature range between 300-600°C to combine N_2 and H_2 in the ratio of 3:1 at a pressure ranging from 100-350 bar (Bicer, et al., 2017b; Brohi, 2014; Flórez-Orrego & Junior, 2017; Macfarlane et al., 2020; Philibert, 2017; Rouwenhorst et al., 2021; Verleysen et al., 2020). Essentially, the H_2 from SMR or coal gasification and N_2 stripped from air is converted to NH_3 in a reactor – while unconverted syngas is recycled (Klerke et al., 2008). Since the inception of the method, there is a sporadic and continuous changes in the design of NH_3 synthesis reactors; yet limitations of the techniques including unfavorable thermodynamic equilibrium for NH_3 synthesis resulting in low yields per pass through the converter, hasn't been solved (Allman et al., 2017; Bartels & Pate, 2008; Jarullah et al., 2013). However, the energy intensive process now accounts to 90% of world's NH_3 manufacturing (Bartels & Pate, 2008; Yilmaz & Ozturk, 2022).

Global NH_3 plant capacity in the 1950s were a few hundred tons/day, which grows to an annual volume of 130 MMT in 2000, 133 MMT in 2008, 205 MMT in 2010, 235 MMT in 2019 and 239 MMT in 2020 (Anantharaman et al., 2012; Ghavam et al., 2021; Gosnell, 2005; Morgan, 2013; Siddiq et al., 2011). With an annual increment ranging from 1.67-2.3% in the last few years, its estimated value is put at 100 billion USD with 226 MMT average annual production between 2010-2020 (Brightling, 2018; Macfarlane et al., 2020; Smith et al., 2020; Zhang et al., 2019). First NH_3 plant was constructed by the German firm, BASF at Oppau, in 1913 (Pattabathula & Richardson, 2016; Rouwenhorst et al., 2022). After then, several other plants of higher capacities (Table 1) were developed, the largest being able to produce 3300 mtpd or 3640 stpd (Brightling, 2018).

Table 1: Capacities of Some Ammonia Plants and their Year of Construction

Ammonia Plant	**Capacity at Inception**	**Current Capacity**	**Location**	**Year of Construction**	**Reference**
BASF	30 mtpd	875000 mtpy	Oppau, Germany	1913	(Pattabathula & Richardson, 2016)
Hydro Agri, Sluiskil E-Braun License	1750 mtpd	-	Sluiskil, the Netherlands	1988	(Russo et al., 2010)
BASF- Uhde License	1800 mtpd	2060 mtpd	Antwerp, Belgium	1991	(Larsen & Lippmann, 2002)
Jiujiang Chemical Fertilizer Plant	300,000 mtpy	-	Jiangxi Province, China	1996	(Jiang et al., 2005, 2008)
RCF-Haldor Topsoe (Denmark) & Benfield Corporation (USA)	900 mtpd	2200 mtpd	Rashhtriya Chemicals & Fertilizer (RCF) Ltd, Bombay	1982	(Sharma, 1989)
P.T. Kaltim Pasifik Amoniak- Haldor Topsoe License	2000 mtpd	2700 mtpd	Bontang, Indonesia	2000	(Christensen, 2001)
Profertil S.A. Fertiliser Plant	2050 mtpd	**775000 tons**	Bahia Blanca, Argentina	2000	(Brigden & Stringer, 2000)

Ammonia 3 Plant/Juraj Dimitrov Bratislava Nitrogen Factory Sala-Uhde Technology	1300 mtpd	200000 mtpy	Former Czechoslovak Republic	2003	(Kessler et al., 2006)
Burrup Fertiliser Private Limited (BFPL)-KBR License	2200 mtpd	2200 mtpd	Burrup, Australia	2005	(Jovanovic et al., 2006)
Saudi Arabian Fertilizer Company (SAFCO)- Uhde license	3300 mtpd	3670 mtpd	Al-Jubail, KSA	2006	(Ruther et al., 2005)

It has been speculated that a 4000 mtpd is possible based on Uhde Technology (Ojha & Dhiman, 2010; Ruther et al., 2005). According to Arora et al. (2016), 1000 tpd ammonia plant is capable of meeting the demands of several small countries. However, for 1000 mtpd NH_3 plant, ≅ 3100 mol/hr of gaseous NH_3 is produced in NH_3 converter at about 440°C and 150 atm pressure (Rahman et al., 2014). The pilot scale NH_3 plant at West Central Research and Outreach Center at the University of Minnesota, 11 plants in Canada generating 4-5 mtpy of NH_3 and an ammonia plant at Billingham, UK are few examples of prominent plants in the world (Allman et al., 2017; Zamfirescu, et al., 2017; Brightling, 2018).

Methods of producing NH_3 by reforming methane are steam reforming, partial oxidation, autothermal reforming, dry reforming and the electrolysis of water (Rice & Mann, 2007). SMR of hydrocarbons to carbon monoxide (CO), CO_2 and H_2 for NH_3 production was introduced in 1930 where the choice of feedstock for the reforming process largely depends on its location, availability, and the local energy policy (Bhaumik et al., 2002; Quon, 2012; Ramos & Zeppieri, 2013). Advantages of the method are namely, simplicity, lower cost, its environmentally friendliness, high conversion efficiency, low process operation temperature, high feedstock hydrogen-to-carbon ratio and its widespread utilization (Bhaumik et al., 2002; Vezina, et al., 2017). Industrial scale production of NH_3 using this technique comprises of six main interconnected stages; namely desulphurization, steam reforming of natural gas (methane, CH_4), shift conversion, CO_2 removal (Chaudhary et al., 2017), methanation and NH_3 synthesis. Two reformers called the primary and secondary reformers are employed during NH_3 production and have been used practically in Camargo City Chihuahua State, Mexico and the Billingham NH_3 factory in the 1920-1930s (Brightling, 2018; Flores et al., 1997). In the primary reformer, naphtha is cracked into C and H by heating the fluid over a catalyst loaded tube, given that the reformer makes exhaustive use of heaters (Bhaumik et al., 2002; Flores et al., 1997). To reduce the energy being consumed, a reformer-exchanger system can be used after which its effluent is passed to a secondary reformer, where N_2 for the synthesis is added through a pressurized preheated process air (Cremer, 1980; Flores et al., 1997; Ruddock et al., 2003). Vezina, et al. (2017) compared 15 different methods of generating NH_3 in their work. Several others try to simulate an NH_3 plant of varying capacities using ASPEN Plus, ASPEN Hysys and Industry Design Softwares at steady state mode, making several assumptions (Abdel El Moneim et al., 2018, 2020; Azarhoosh et al., 2016; Chidozie & Koyejo, 2021; Islam et al., 2010; Nwanam et al., 2020; Sulaikha & Soloman, 2021; Tripodi et al., 2018). Previously, a calcium-copper process and process condensate stripper had been integrated into NH_3 plant production (Baboo, 2022a; Martinez et al., 2017). These modifications or innovations are centered towards achieving a state-or-the-art facility with advanced technology (Levy, 1989; Shannahan, 2000). After commissioning, various power source are used during NH_3 plant start-up and operation, including wind, solar and hydrothermal power electricity source (Chun & Barton, 1999; Habermehl & Gill, 2015; Moffatt & Sridharan, 2002; Verleysen et al., 2020; Yuksel et al., 2022). Baboo (2022c) states that, no power plant is 100% efficient in converting fuel chemical energy to electrical energy capable of performing valuable task and that the optimum theoretical efficiency of most fossil fuel power stations is around 64%.

Methodology

Materials

Aspen Plus version 8.4 was used for the modeling, simulation and control of the process units. Microsoft Visio 2016 Professional (PC) was used to draw the process flow diagram as well as the instrumentation and control diagram. Windows 10 Pro Portable Laptop Computer (DESKTOP-8GVIVAF), with installed RAM of 4GB, 64-bit operating system, and an Intel(R) Celeron(R) CPU processor containing the listed softwares was used throughout the work. Simple basic numerical computations were carried out using Porpo Programmable Calculator. The process layout and other graphical representations were developed using Wondershare EdrawMax version 11.0.

Process Description

NH_3 production process was divided into three major categories: (1) preparation of raw synthesis gas following the steps beginning with desulphurization of natural gas, primary reforming and secondary reforming, (2) raw synthesis gas purification section including high temperature shift (HTS) conversion, low temperature shift (LTS) conversion, CO_2 removal and methanation sections and, (3) synthesis and refrigeration section including NH_3 conversion and NH_3 separation and storage which is described as the heart of the process by Azarhoosh et al. (2016). Main steps followed for NH_3 process simulation using ASPEN Plus is shown in Figure 1 (Islam et al., 2010; Usmonovich & Elmurodugli, 2022).

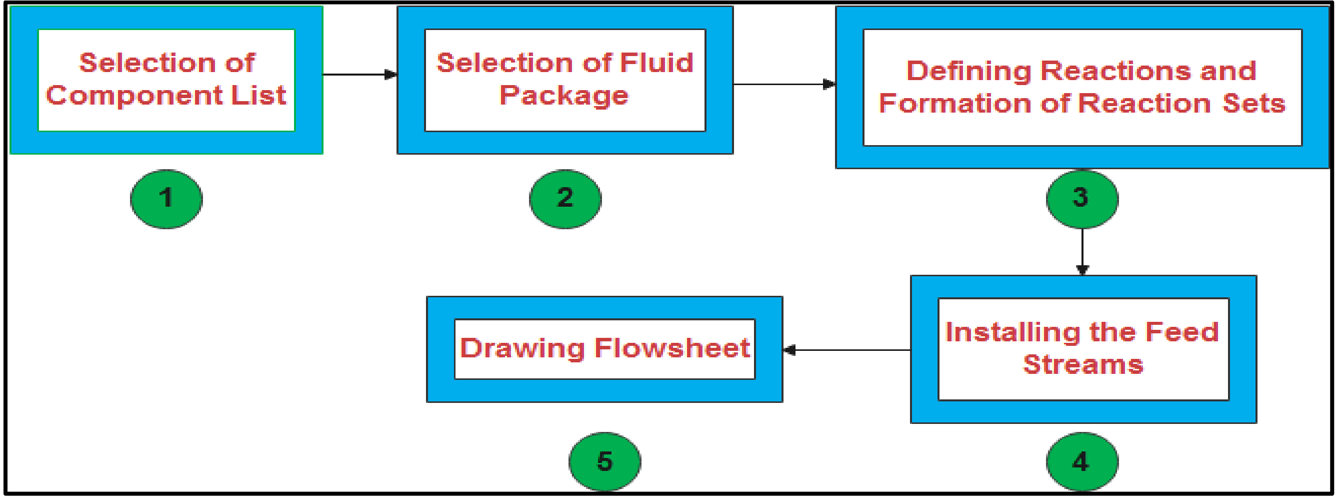


Figure 1: Ammonia Process Simulation Steps Using ASPEN Plus

Input Stream Fractions Specifications

6800 kmol/h of natural gas with component compositions in mole fractions (Table 2) was used in the feed stream. This value was realized based on pre-estimation of the targeted output of NH_3 – put at 200 tonnes/day, even though any amount of the product realized at the end of the process can be scaled-up or scaled-down to pre-set value.

Table 2: Inlet Specification

Components (i)	Molecular Weight (MW)	Mass fraction (x)	Mole fraction (y)
CO_2	44	0.02	0.005
H_2	2	0.1	0.511
N_2	28	0.126	0.047
CH_4	16	0.6	0.3875
Ar	40	0.002	0.0005
S	32	0.153	0.049

The molar specifications in Table 2 wasn't taken from any country's natural gas constituent molar fractions, as different natural gas producing company across the world have specific gas compositions of the natural gas they produce (Denys & Vries, 2013; Kidnay et al., 2015). Together with molar feed flow rates, the compositions were initialized in ASPEN plus. For the feed stream as well as in subsequent calculations for other streams, molar flows of each specie, $\dot{n}_i$ were calculated using Equation (1):

$$y_i = \frac{\dot{n}_i}{\dot{n}_T} \quad \text{OR} \quad \dot{n}_i = y_i \dot{n}_T \tag{1}$$

Mass flows ($\dot{m}_i$) of all gases was computed using Equation (2) from which the mass fractions (x) were determined by substituting in Equation (3):

$$\dot{m}_i = \frac{\dot{n}_i}{MW_i} \tag{2}$$

$$x_i = \frac{\dot{m}_i}{\dot{m}_T} \tag{3}$$

where, subscript i = component gas, $\dot{n}_i$ and $\dot{m}_i$ = molar and mass flows of components i, respectively and $\dot{n}_T = \sum \dot{n}_i$ and $\dot{m}_T = \sum \dot{m}_i$ = total molar and mass flows in the stream.

Natural Gas Desulphurization

Natural gas was preheated in a pre-heater **E-01** to 350-400°C from the well sources. It was then compressed in a compressor **C-04** at a pressure of about 43.5 atm, before it was sent through stream **002** to the desulphurizer, **R-01** for the removal of impurity where sulphur (S) compounds are hydrogenated to hydrogen sulphide (H_2S). Cobalt molybdenum catalyst was used in Reaction 4 in 99% conversion of S.

$$H_2S + ZnO \rightarrow ZnS + H_2 \qquad (4)$$

The mixture was further sent to the separator unit **S-02** were the H_2S is removed (no H_2S in stream **043**). At this point, the S content was removed to < 0.1 ppm in the gas feed and the ZnO remains in the absorption bed.

Primary Reforming

At this stage, process gas from the desulfurizer passes through stream **043** to a mixer **M-01**, which is mixed with incoming steam in stream **004**. Stream **004** is 100% steam (hot H2O) injected at a flow rate of 100 kg/h. The mixture was heated to further 500-600°C in a heater **E-02** before it goes to the primary reformer unit **R-02** containing nickel catalyst. In the primary reformer, the heat supplied was a result of burning natural gas or other gaseous fuels in the fired heater **E-03**. How to select the best fuel that would results in optimal production was previously explained by Nie (1995). Amount of natural gas (fuel) supplied initially per hour was approximately 10 kg. The flue gas leaving the fired heater **E-03** was at a temperature of 900°C, and steam/carbon ratio is 3.0. It is worthy pf note that the stage is highly endothermic. The reformer was operating at a temperature of about 880°C and a pressure of about 25atm. Governing reaction in this unit is given in Reaction (5) and (6), as taken from literature.

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2 \qquad \Delta H°_{298} = 206\ \mathrm{kJ.mol} \qquad (5)$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad \Delta H° = -41\ \mathrm{kJ.mol} \qquad (6)$$

Equilibrium constants for steam-methane reforming process for the two reactions as obtained from (Abbas, Dupont, & Mahmud, 2016) are as follows for the above reactions: $k_{eq,4.2} = e^{\frac{-35735.2}{T}+30.114} = \frac{y_{CO} \cdot {y_{H_2}}^3}{y_{CH_4} \cdot y_{H_2O}}$ and $k_{eq,4.3} = e^{\frac{4400}{T}-4.1027} = \frac{y_{CO_2} \cdot y_{H_2}}{y_{CO} \cdot y_{H_2O}}$ where T implies temperature in Kelvin. Majumdar & Mukherjee (1988) wrote on the influence of steam injection in primary reformer to the energy efficiency of the overall plant. Failure analysis of NH_3 plant primary waste heat boiler and energy-intensive design of the SMR furnace were previously carried out by Ardy et al. (2021) and Zecevic (2021) respectively.

Secondary Reforming

This reformer was simulated based on method described by Yu et al. (2006).Synthesized gas from stream **009** was cooled to 735 ℃ in a cooler **E-04**. It was mixed with compressed air (50 kg) from compressor **C-01** at a pressure of 38 atm in mixer (**M-04**). Normally, air is a mixture of 21% O_2, 78% N_2 and 1% argon, and though not present in stream **010**; amount of air in stream **012** is equal to air in stream **042**. The mixed stream flows down to the secondary reformer **R-03** (Yu, 2002), where as usual the reaction at that stage was considered highly exothermic, operating at 880°C. Ratio of the natural gas (mainly CH_4) to that of steam must be less than 0.5 to prevent coking in the pre-heater. Equilibrium reaction (7) and (8) governing this unit was entered in ASPEN Plus.

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad (7)$$

$$H_2O + CH_4 \rightleftharpoons CO + 3H_2 \qquad (8)$$

Catalyst used at this point was pure iron, even though there are several other catalysts (e.g. nickel oxide) that can be separately evaluated for efficient performance of the secondary reformer (Al-Dhfeery & Jassem, 2012). Water, CO and CO_2 must be removed from the syngas through stream **014** to prevent oxidation of the iron. It is worthy of note that, appropriate design and operating principles must be followed as secondary reformers may sometimes fail, catch fire or explode (Lestari et al., 2019; Mittal & Arvindakshan, 1994; Taghipour et al., 2021).

High Temperature Shift (HTS) Conversion

Synthesis gas from stream **013** usually contains poisonous gas like CO which is poisonous to catalyst. Incoming syngas was cooled to 400°C in a waste steam cooler **E-05**. Process gas from the secondary reformer contains 12-15% of CO, most of which is converted in the high temperature shift reactor **R-04**, consisting of bed of iron/chromium oxide catalyst through which the gas passes through. Reaction occurs at a temperature of 400°C where CO is reduced to 3%. Shift conversion was basically used to condition the syngas to desired ratio and the HTS conversion reaction is given by Reaction (9).

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad (9)$$

Low Temperature Shift (LTS) Conversion

Gas from the HTS converter **R-04** was cooled to 200-220°C, in a cooler **E-06** and then passed through stream **016** to the LTS converter **R-05**. LTS converter operates at a temperature of 200℃, which was filled with zinc-oxide based catalysts. Optional stream might contain most of S from stream **016** (say 98% of S) together with negligible amount of H_2O (say 0.07%). Water (100kg/h equivalent to 100%) from the exchanger **E-07** was mixed and sent back to the HTS converter **R-04.** In mixer, **M-02**, stream **037** is a recycle stream of solely water (100kg/h = 5.556 kmol/h). Reaction 10 is the LTS conversion reaction as specified in ASPEN Plus.

$$\mathrm{CO} + \mathrm{H_2O} \rightleftharpoons \mathrm{CO_2} + \mathrm{H_2} \tag{10}$$

Absorption/Regeneration Unit

Synthesis gas from the LTS converter (consisting mainly of H_2, N_2 and CO_2) passes through stream **017** to an exchanger unit **E-07** which cools the gas before sending it to the absorber column **CLM-01** through stream **018**, were the CO_2 is dissolved and sent to the generation column **S-03**. Afterwards, the CO_2 is recovered for other industrial process (including sales). Basic solvent used for CO_2 absorption is the aqueous amine solution, Mono-Ethanolamine (MEA). In the solvent storage tank, **T-01**, MEA absorbing capacity of CO_2 is 4.123 mol% (CO_2 **:** MEA = 0.04123). All CO_2 entering **CLM-01** through stream **018** was absorbed. MEA solution was pumped to the column **CLM-01** through stream **034**. The absorber overhead (stream **022**) was assumed to having no trace of CO_2 while 70% of the solvent (MEA) leaves same stream. Stream **019** is completely MEA and CO_2. A 100% pure CO_2 and MEA-OUT of unit **S-03** was targeted.

Methanation and Ammonia Synthesis

After CO_2 absorption, there exist little amount of CO and CO_2 in the synthesis gas passing through stream **022** from the column absorber **CLM-01** which are also considered to be poisonous for the NH_3 synthesis catalyst, and has to be removed by converting the CO and CO_2 to CH_4. The conversion is done in the methanation reactor **R-06** via Reaction (11) and (12) (Asante et al., 2022).

$$\mathrm{CO} + 3\mathrm{H_2} \rightarrow \mathrm{CH_4} + \mathrm{H_2O} \tag{11}$$
$$\mathrm{CO_2} + 4\mathrm{H_2} \rightarrow \mathrm{CH_4} + 2\mathrm{H_2O} \tag{12}$$

Equilibrium constant for reactions 11 and 12 was taken as $k_{eq,4.8} = 0.0007349$ and $k_{eq,4.9} = -0.5855$ respectively. The reactions took place at around 300°C were the reactor **R-06** is filled with nickel catalysts. Gas from the methanator **R-06** was cooled in a cooler **E-08** and then compressed in a single stage compressor **C-03** before channeling to the ammonia converter **R-07**. Syngas from the NH_3 reactor was cooled to 30°C in a cooler **E-09**. Waste gases were purged through a purge stream. Remaining constituents were sent to the separator **S-01** through stream **030** were the unreacted gas are recycled back to mixer **M-03** through stream **031** leaving the NH_3 gas as the output product from stream **033**. It was expected that the recycle stream **031** contains 0.0156% CO_2, 41.68% H_2, 0.174% N_2, 50.69% CH_4, 0.00675% Ar, 0.00127% S, 0.652% H_2O, 6.702% MEA and 0.0331% air in mole basis equal to a mass flow of 161687.942 kg/h in that stream.

Ammonia Synthesis Reaction

Synthesis of NH_3 (in Reaction 13) takes place on an iron catalyst at a pressure usually in the range 100-250 bar and a temperature of 350 °C (El-Gharbawy et al., 2021), even though previously, Liu et al. (2020) developed and applied a new catalyst to synthesize NH_3. Previously, Al-Malah et al. (2018) developed a successful simulation of an NH_3 synthesis process that generates NH_3 at low temperature and pressure using Aspen. Amount of CO_2 and CO coming to stream **028** was reduced to percentages; say 85.11% and 83.9% respectively.

$$\mathrm{N_2} + 3\mathrm{H_2} \rightleftharpoons 2\mathrm{NH_3} \qquad \Delta\mathrm{H} = -46\mathrm{kJ.mol^{-1}} \tag{13}$$

It was assumed that in the splitter **SPLT**, (1): 2% of CO_2 and CO in stream **030** are purged and (2): 70% of H_2, and NH_3; 58.56% of N_2; 69.81% of CH_4; 24.85% of argon; 69.82% of S and H_2O; 69.81% of MEA and 69.77% of air in stream **030** is contained in stream **041**. Previously, researchers has demonstrated the possibility of removing/recovering/recycling H_2, N_2 and NH_3 from ammonia plant waste stream or purge gases in order to increase the plant's capacity (Rahimpour & Asgari, 2009; Rahimpur & Asgari, 2008; Roos et al., 2001; Safari et al., 2021). Unburnt hydrocarbons, SO_2, C (flyash, particles) in boilers, CO, NOx and CO_2 are the main pollutants (by-products) from NH_3 plants (Baboo, 2022c, 2022b). In separator **S-01**, most of the components are recycled as stream **031** (fresh feed to **M-03**) excluding NH_3.

Summary of the units involved, their code/number and their representative streams is presented in Table 3.

Table 3: Nomenclature of Units Employed and Their Streams Constituents

S/No.	Units	Operation	Input Stream(s)	Output Stream(s)
1.	E-01	Natural Gas Preheater	Natural Gas	039
2.	C-04	Natural Gas Compressor	039: Preheated NG	002: Compressed NG
3.	R-01	Desulphurizer	002	003: Desulphurised NG
4.	S-02	H_2S Removal	003	043: Sweetened NG H2S: Removed

5.	M-01	Steam & Syngas Mixer	043 004: Steam Addition	005: Mixed Steam + Syngas
6.	E-02	Steam & Syngas Pre-heater	005	006: Preheated 005 Stream
7.	E-03	Fired Heater	Fuel	008
8.	R-02	Primary Reformer	006 008: Combusted NG Fuel	009: Syngas Generated
9.	E-04	Primary Reformer Cooler	009	010: Cooled Syngas
10.	C-01	Air Compressor	Air	012: Compressed Air
11.	M-04	Air & Syngas Mixer	010 012	042: Air & Syngas Mixing
12.	R-03	Secondary Reformer	042	013: More Syngas Generation/CH_4 Reduction
13.	E-05	Waste Steam Boiler	013	014: Syngas Cooling
14.	M-02	Syngas & Water Mixer	014 037: Recycled Water	038: Mixed Syngas & Water
15.	R-04	High Temperature Shift Converter	038	015: Reduced CO
16.	E-06	HTS Cooler	015	016: Cooled 015
17.	R-05	Low Temperature Shift Converter	016	017: Reduced CO
18.	E-07	Syngas Heat Exchanger	017 007: Water Addition	018: Mainly H_2, N_2 and CO_2 Product 037
19.	T-01	MEA Tank	-	034: MEA supply
20.	CLM-01	CO_2 Absorber	018 034	022: Highly H_2 and N_2 Product 019: MEA + CO_2 Stream
21.	C-02	Syngas Compressor 1	022	023: Heated 022
22.	S-03	CO_2 Removal	019	021: CO_2 Removal OPT
23.	R-06	Methanation	023: Highly H_2 and N_2 Stream	024: Highly CH_4, H_2 & N_2 Product
24.	M-03	Natural Gas & Recycled Syngas Mixer	024 031: Unreacted Gas Recycle	040: Mixed 024 & 031
25.	E-08	Syngas Condenser	040	025: Heated Mixture
26.	C-03	Syngas Compressor 3	025	027: Compressed Syngas
27.	R-07	Ammonia Conversion	027	028: Highly NH_3 Output
28.	E-09	Syngas Cooler	028	030: Cooled Product
29.	SPLT	CO_2 & CO Purger	030	Purge: CO_2 and CO 041: Remaining Composition
30.	S-01	Ammonia Separation	041	031 033: NH_3 Product

Material and Energy Balance

Using appropriate energy balance relations (Cremer, 1980; Ghasem & Henda, 2015), the heat flows in and out of all streams was computed. In addition, mass and mole balances as well as heat balances over all units and the entire process was carried out using auxiliary information of the process description, as well as equations from Ghasem & Henda (2015). Important calculations done here also follows a detailed material balance calculations presented for an ammonia plant design by Baniya (2021).

Process Optimization, Instrumentation and Control

Flexible ASPEN Plus features were utilized to optimize the recovery of NH_3 and other intermediate products. Optimization (Anon, 1987) was carried out on four important units which are the **R-01**, **R-03**, **R-04**, **R-06** and **R-07**. Equipment used for the NH_3 production process by steam reforming were heat exchangers, reactors, mixers, separators, storage tank, compressors and absorbers, most of which requires control of their process conditions. Key control parameters identified were temperature, methane slippage, H/N ratio, steam/carbon ratio and pressure. Kinds of controllers suitable for the common variables are PI (for flow and liquid pressure), P (for gas pressure), P or PI (for liquid level), PID (for temperature) and P, PI & PID (for composition), where P, I and D implies proportional, integral and differential controllers.

Plant Layout

A simple layout showing the plant area, utilities, canteen, future expansion and roads and car parking areas was developed.

Results and Discussion

The flow diagram containing results of heat and energy balances (Cremer, 1980; Graeve, 1981) carried out on all units of the plant after interpreting the process described above was produced. Figure 2 was produced using Microsoft Visio. It depicts material and heat flows from every stream as well as their process conditions.

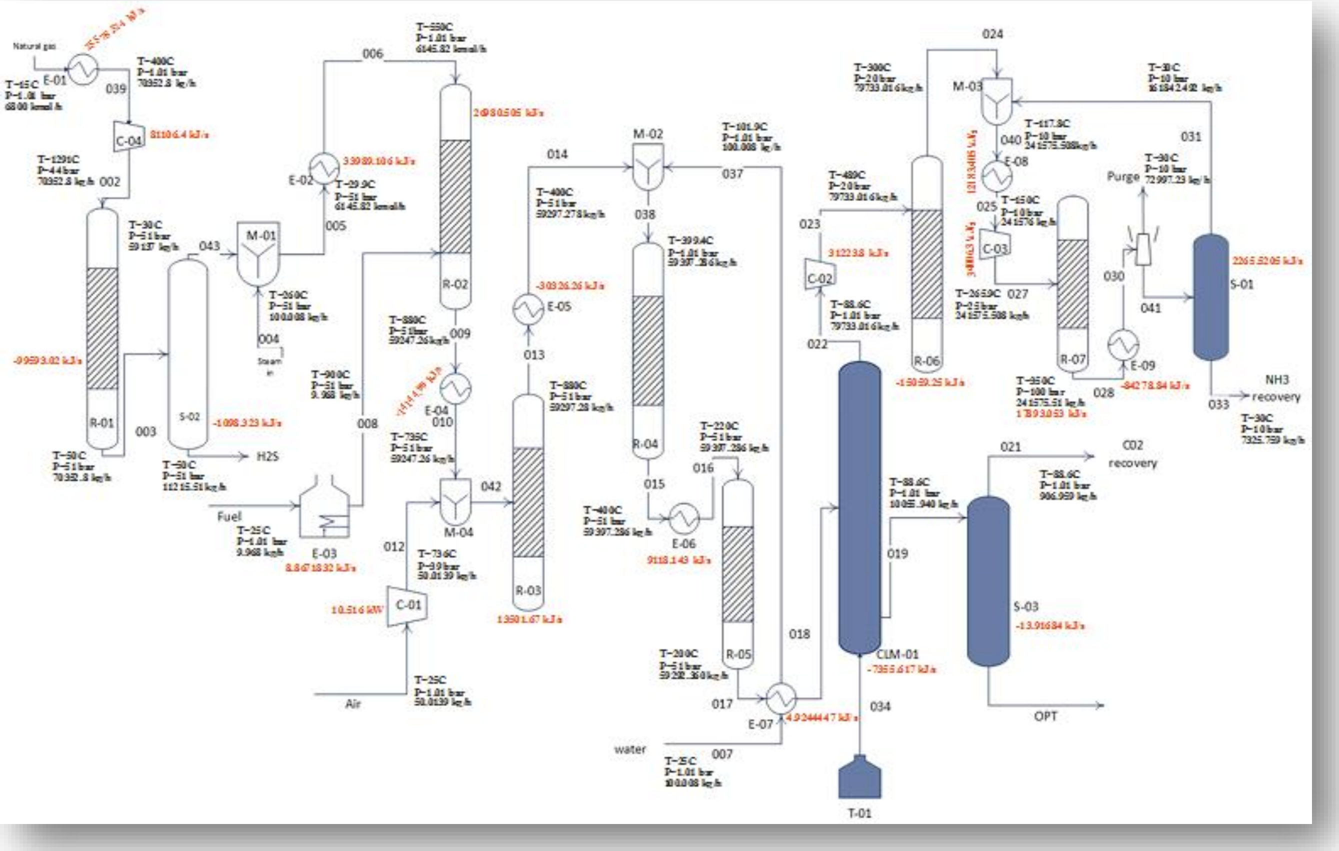


Figure 2: Process Flow Diagram of the Ammonia Plant

It was simulated using ASPEN Plus V.8.4 following some techniques used by Nwanam et al. (2020) during the simulation of the Indorama ammonia plant, which resulted in the output mass and heat flows shown in Figure 2. Output of NH_3 from **S-01** product stream was 7325.759 kg (430.927 kmol) which was then scaled-up to 200 tons/day using a scale-up factor of 1.1375, as small sized plants could be scaled-up to a large size one when necessary (Axelrod, 2006; Ramos & Zeppieri, 2013; Sanchez & Martin, 2018; Vrijenhoef, 2017) reported that there is currently in existence, about 105 large-scale plants ranging from 600-1800tpd in practically every corner of the world, which is apparently close to this capacity. According to Panjeshahi et al. (2008), the recovery of fairly small amount of heat has the ability to accrue into a sizeable energy savings, as NH_3 manufacture is voted as an energy intensive technique. For all heat exchangers present, the second law via Pinch Technology gives the thermal interactions between the chemical process and utility systems that surrounds them to improve utility consumption (Ozturk & Dincer, 2021;

Tavares et al., 2013). Lababidi et al. (2000) and Lundgren (2016) carried out a detailed energy integration study using Pinch Technology on an NH_3 plant configurations prior to final detailed simulation and optimization. To verify that the minimal requirements of utilities, heat transfer area, and total cost are met, a retrofitting analysis of an existing network of chemical plants can be conducted (Chavda, 2019). Hanada et al. (2010) findings show that, if natural gas is used as feedstock to produce NH_3, 28.5 MJ/kg NH_3 (based on lower heating value) would be consumed. How energy in an NH_3 plant can be calculated using designed equations is detailed by Baboo & Manager (2015).

Optimization Output

In the literature, Flórez-Orrego & Junior (2017) carried out the modelling and optimization of an NH_3 synthesis plant. Using the same idea, 200 tons capacity NH_3 plant was optimized for maximum productivity and efficiency. Firstly, S content in **R-01** was minimized at the outlet stream thereby increasing the yield of H_2S. To ensure that S is minimized, sensitivity analysis was carried to obtain the variables that may likely affect the flowrate of the outlet stream. From Figure 3, it was observed that the output molar flow of H_2S increased with an increase in fractional conversion, obviously asserting the fact that, the yield of H_2S is sensitive to its corresponding fractional conversion, even though there are other variables that may likely have effect on its production. Therefore, the optimum conversion that optimizes the yield of H_2S is obviously 0.999.

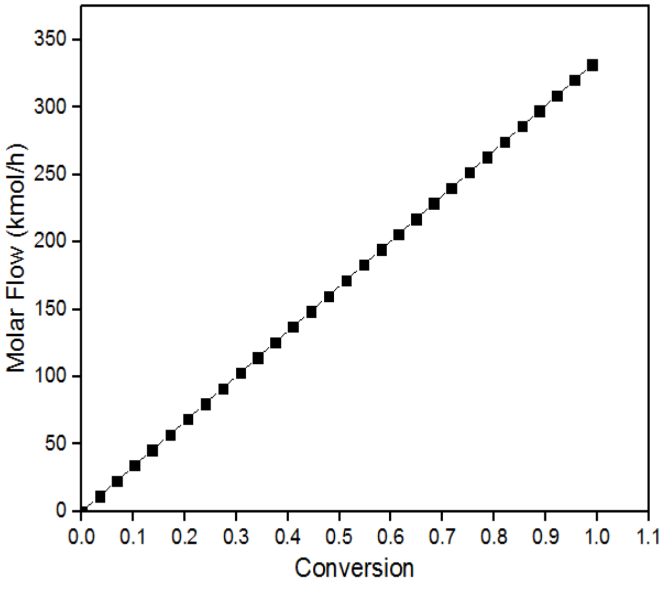


Figure 3: Effect of Conversion on Sulphur Minimization in R-01

Yield of H_2 can be maximize in reactor **R-03**. Sensitivity analysis carried out to identify the process variable capable of affecting the process unit using ASPEN plus software, shows that temperature has drastic effect on the yield of H_2 production. From the analysis, a throughput temperature gave an increment of 3% to 10% of H_2 in the outlet stream, thereby asserting the optimum value for the production of hydrogen to be 1200℃. Figure 4 illustrates this analysis.

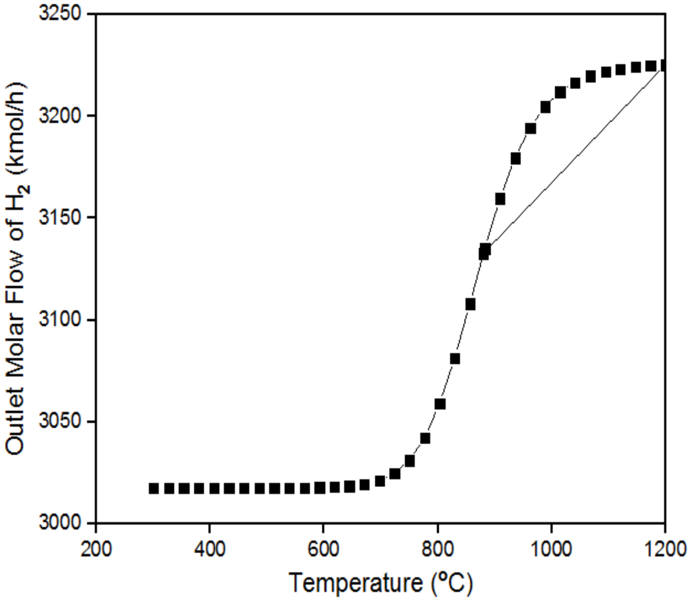


Figure 4: Temperature Effect on Hydrogen Yield

Meanwhile, sensitivity analysis carried on reactor **R-04** shows that for every decrement in the reactor temperature there is an increment in the outlet flowrate of CO_2 (Ali et al., 2010). It proves the fact that, the optimum temperature capable of maximizing the yield of CO_2 is found within temperatures of lower limit (20℃) rather than having a high temperature for the equilibrium reaction taking place in the reactor, as shown in Figure 5.

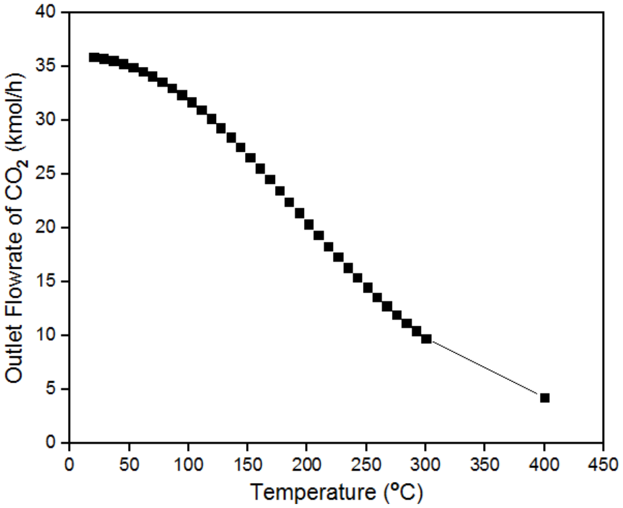


Figure 5: Effect of Temperature on CO_2 Production in R-04

Also, CH_4 can be maximized by minimizing CO in the outlet stream of **R-06**. Sensitivity analysis carried on **R-06** points to an increase in temperature as responsible for a proportional increase in the molar flow rate of CO. Consequently, optimum temperature required to use up CO, lies within the lowest temperature limit (like 250°C); and emphasizes a decrement of about 10-15% of CO in the outlet stream of the reactor, as clearly depicted in Figure 6.

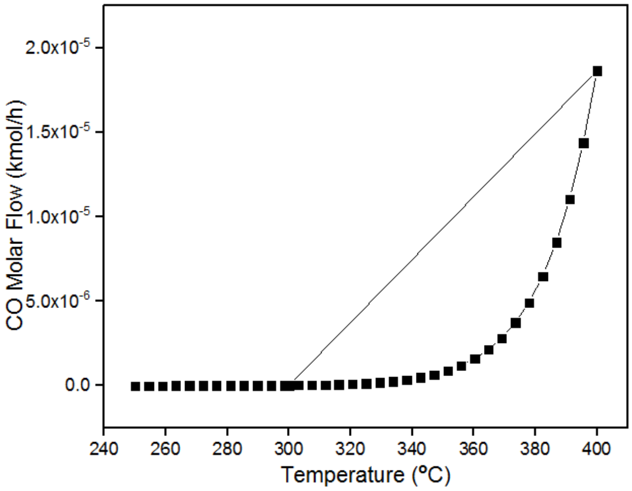


Figure 6: Influence of Temperature on CO Yield

Foremost product of the plant, NH_3, can also be maximized by testing for temperature sensitivity in the reacting system of **R-07**, in accordance with Ivanov (2017) and Bland (2015). From the analysis, there is a 10-12% increment in NH_3 yield with decrease in temperature. Thus, the decision variables are meritoriously the operating temperature of the reactor; and the optimum temperature lies within the possible temperature limit of the reactor (230.589°C), which is very obvious in Figure 7.

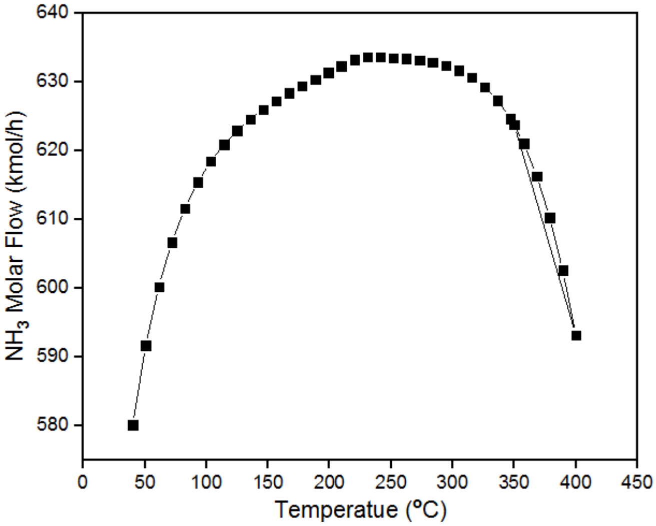


Figure 7: Illustrating the Effect of Temperature on NH_3 End-product

Previously, Tripodi et al. (2018) simulates NH_3 manufacture over Ru/C catalyst, Azarhoosh et al. (2016) uses Genetic Algorithm to simulate a horizontal reactor for NH_3 synthesis, Chehade & Dincer (2021) as well as Lundgren (2016) modeled kinetically, a small modular NH_3 unit, while Chidozie & Koyejo (2021) follows a step-wise approach that involves data collection and ASPEN Hysys simulation of an NH_3 plant front-end waste heat boilers.

Process Control

Control in process industries refers to the regulation of all aspects of the process. In real chemical plants, steady-state doesn't exist. Things are always changing. Process control is concerned with making sure that processes perform their tasks in a safe and economical way (Frahm et al., 2001; Grasdal et al., 1998). Process control technology is the tool that enables manufacturers to keep their operations running within specified limits and to set more precise limits to maximize profitability, ensure quality, minimize risk and ensure safety (Novandhini et al., 2020; Ojha & Dhiman, 2010). Control performance depends on the quality of the used Instrumentation and Control (I&C) infrastructure (i.e. sensors, control system hardware and actuators) using the Distributed Control System (DCS) originally designed for process plants (Araujo & Skogestad, 2008; Borikar, 2018; Dziuba et al., 2020). The whole process I&C diagram is as shown in Figure 8.

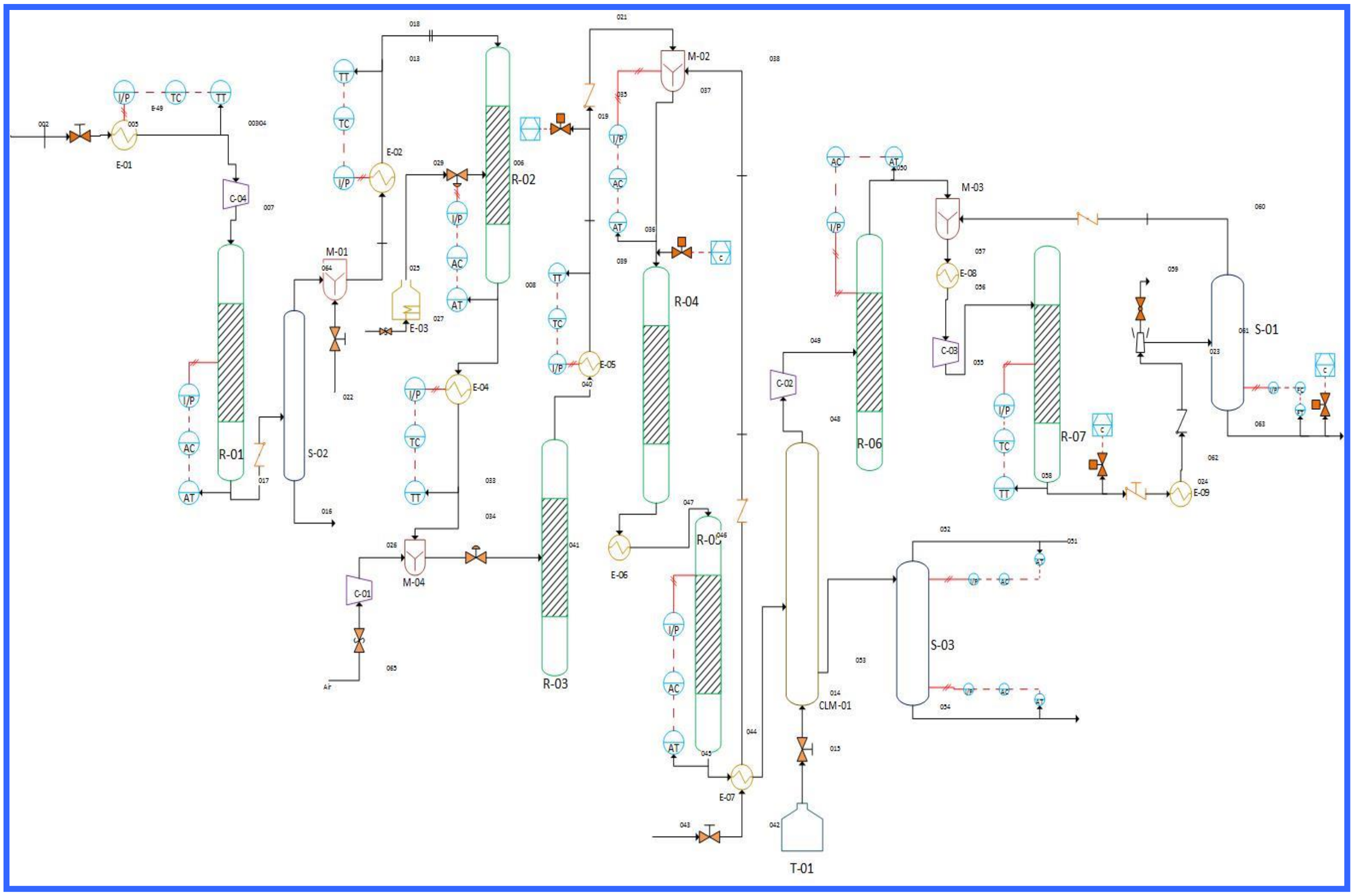


Figure 8: Piping and Instrumentation Diagram

Sulaikha & Soloman (2021) collectively carry out the control of reactor, level, separator and pressure in their work using almost the same approach described in this work. The control objective of **R-02** is to maintain a steam/carbon ratio of 3:1 using compositions of H_2O and CH_4 as control variables. Steam and natural gas reacts in the primary reformer to form H_2 and CO ($CH_4 + H_2O \rightarrow 3H_2 + CO$). Some of the CO will react with the steam to form even more H_2 ($CO + H_2O \rightarrow CO_2 + H_2$). Thus, steam-to-carbon gas ratio requires tight control because energy is wasted when excess steam is produced unnecessarily. In addition, excess CH_4 requires more energy for compression and causes inefficient catalyst activity (Dark & Stallworthy, 1985). A minimum ratio of 3 kmol steam to 1 kmol of carbon, i.e. 3:1 should be maintained. Tight control of the steam to carbon ratio can significantly decrease production costs. The first reaction is endothermic, where an increase in temperature favors formation of the product, which is essential. Decrease in temperature will result in generation of high amount of reactant (steam and CH_4), which is an undesired increase. Malhotra-Kbr et al. (2004) reported an increase in capacity from 1000 mtpd to 1070 mtpd in NH_3 production, despite reduction in natural gas capacity of a primary reformer at Shenzhen Liaohe Tongda Chemicals Company Limited Ammonia Plant, Panjin City, China, when the unit was replaced. Replacement is inevitable in case of reformer tube failure (Bhaumik et al., 2002; Boumaza & El Ketroussi, 1996). The control objective of **R-03** is to increase the conversion of CH_4 by decreasing temperature. It is obvious that only 30-40% of the hydrocarbon is usually converted in the primary reformer. The exhaust is therefore fed into a secondary reformer where the conversion to CO and H_2 continues. It is important to minimize the amount of unreacted CH_4, or methane slippage, from the secondary reformer. If it is not minimized, CH_4 builds up in the NH_3 converter loop which can only be corrected by increasing the conversion of CH_4 to syngas. It is an equilibrium endothermic reaction. Increase in temperature favors the formation of the product (syngas) while a decrease in temperature favors backward reaction (i.e., CH_4 formation). Inlet temperature of 735 ℃ can be reduced to 690 ℃ (setpoint) by adding cooling water.

Control objectives of **R-04** and **R-05** entails the removal of all CO from the process before it enters the NH_3 converter, or catalyst poisoning will occur. This removal takes place by 'shifting' the CO to CO_2 after which the CO_2 is absorbed (Mahmoodi & Darvishi, 2017). This shift occurs in two steps during high and low temperature shifts (Agnesty et al., 2020). If the CO is not properly removed, it can shift back to CH_4, creating a highly exothermic reaction that can damage the next process stage; called the methanator (**R-06**) as clearly exemplified by Alhabdan & Elnashaie (1995).

HTS reaction is exothermic – decrease in temperature will maximize the shifting of CO to CO_2 (according to Le Chatelier Principle) or reduce the amount of CO to a setpoint between 0.1–0.5% concentrations; likewise, in LTS reactor. **R-06** is designed to remove any residual CO and CO_2. Syngas output from **R-06** should be ideally comprised of 75% H_2 and 25% N_2. Production of NH_3 takes place in the converter (**R-07**), vital in the maintenance of the ratio of H_2 and N_2 as close as possible to the stoichiometric ratio of 3:1. **R-07** is governed by the Haber-Bosch reaction 13, where the forward reaction results in a decrease in number of moles, hence decrease in pressure and the backward reaction results in an increase in number of moles hence increase in pressure. According to Le Chatelier's principle, if a high pressure is applied to an equilibrium system, the reaction which involves a reduction in pressure is favored. Conversely, if low pressure is imposed on an equilibrium system, then the reaction which results in an increase in pressure is favored. In the Haber process, forward reaction is exothermic; decreasing the temperature will give a high yield of NH_3. A temperature of 250°C give better yield of NH_3, but is not economically feasible as it takes too much time for the reaction system to attain equilibrium – because the reaction rate decreases as temperature decreases.

Measured variable for a heat exchanger is the temperature of the outlet stream. So, the set points for all eight heat exchangers contained in this design are 400°C **E-01**, 550°C **E-02**, 735°C **E-04**, 400°C **E-05**, 220°C **E-06**, 199.8°C **E-07**, 150 °C **E-08** and 350 °C **E-09**. Even at desired operating conditions, corrosion effects of carbon steels in NH_3 plants heat exchangers must be checked regularly, as they may be caused by the operating temperature, mechanical factors and the corrosive media (Nikitasari et al., 2020; Prifiharni et al., 2020). A separator works on the principle of 'different component having different boiling point'. The most volatile component is collected at the top with low boiling points. Higher boiling point fluids are collected at the bottoms. This control setup aims at making the top and bottom outlet temperatures of the separator be at a set point. Hence, the control variable is temperature of the outlet streams. At the top, the outlet temperature is measured by the temperature sensor transmitter, it sends an electronic signal to the controller which has a setpoint of T_{set} = 88.6°C for separator **S-03**; 30 °C for separator **S-01** and **S-02**. Temperature controller (TC) then, calculates the error signal and sends an output called controller output to current-to-pressure (I/P) transducer to be implemented by the control valve. The same happens at the bottom of the column where their respective setpoints are 30°C for **S-01**, 50°C for **S-02** and 88.6°C for **S-03**.

In all, the controller compares the measured value to the desired value (set point) and calculates an appropriate output signal that is sent to an I/P transducer where it is converted to an equivalent pneumatic (air) signal that is compatible with the control value. As for the mixers, the proportional-integral-derivative (PID) controller is chosen because of its robustness and simplicity in tuning parameters. The process variable or measured variable (MV) is the mixture quality (q), measured by the composition analyzer-transmitter (AT). The mixture quality is defined as the average output concentration of the mixture. The set point is SP as specified by the control engineer. The composition controller (AC) sends a signal, p(t) of the manipulated variable known as controller output to the mixer tank. Disturbance input is the input mass flowrate fluctuations. Absorption is simply the transfer of material from a gas (absorbate) to a liquid (absorbent). Also known as "scrubbing" or "washing". Transfer is based on the preferential solubility of a gaseous component in the liquid. The manipulated, measured, control variables and set points are column inlet flowrate, 450 kmol/h, flowrate and 499.9 kmol/h. In the control loop, FT implies flow transmitter. It senses the flow into the column and measures it. FC is short for feed rate controller. It receives signal from FT, compares it with the given set point and make appropriate corrections to it after which it sends a signal to I/P. I/P then responds by sending pneumatic signal to the final control element for appropriate action.

Plant Layout

Normally, producing a design of any process plant is a highly intricate and demanding task (Peters et al., 2003; Srisukh, 1976; Talarico & Scotto, 2012). Constituting the process layout is crucial part of plant design and one of the most central tasks prior to the plant construction as described by Rahman et al. (2014). Figure 9 depicts the location of the plant area, security units, utilities and other essential units of the designed NH_3 plant.

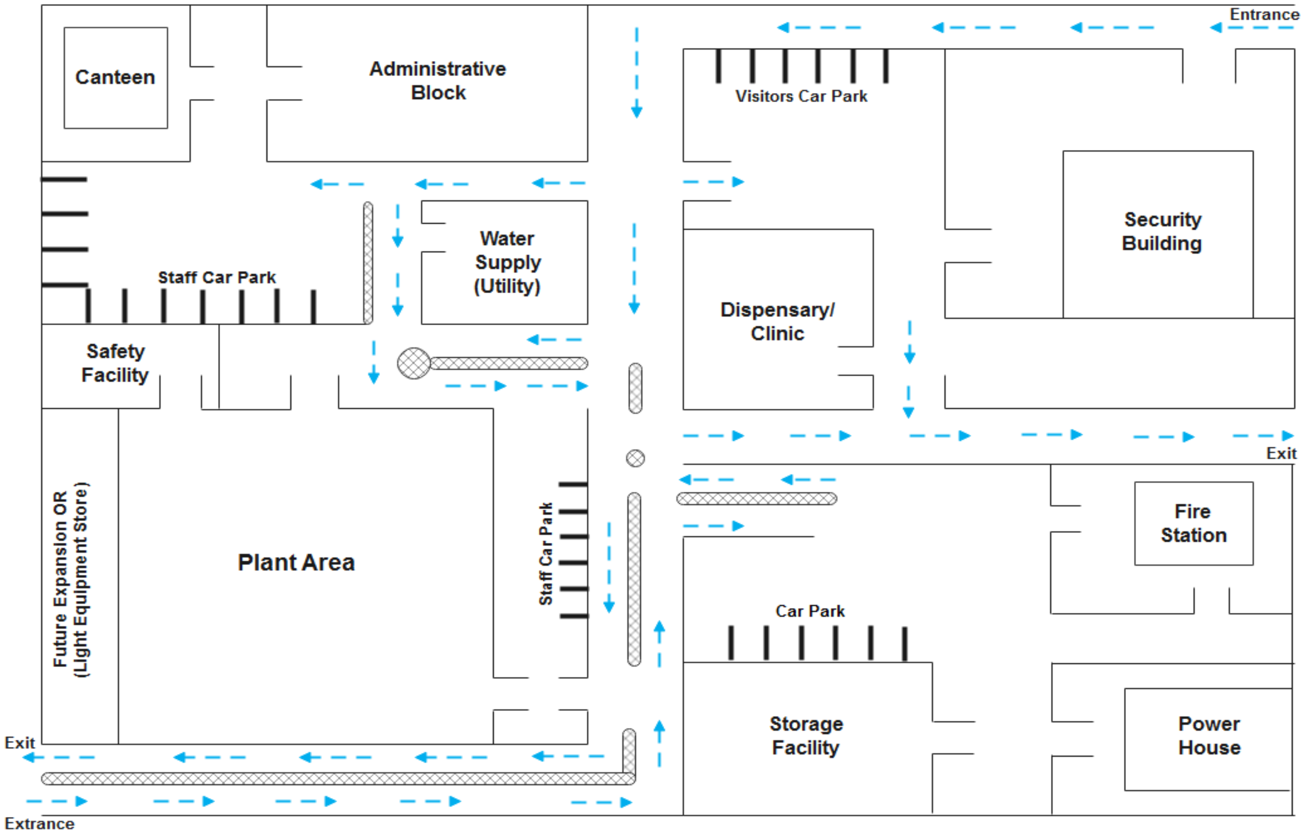


Figure 9: Proposed Layout for the 200 TPD Ammonia Plant

For example, Rahman et al. (2014) produces the layout of an existing NH_3 plant of Karnaphuli Fertilizer Company Ltd (KAFCO) at Rangadia, Karnaphuli, Chittagong-4000, Bangladesh, occupying a total processing area of 123m×106m = 13,038 m^2. Also, a plant layout by Baniya (2021) for an ammonia plant considers siting the pipe bridges, loading and off-loading facilities, plant roads, future expansion, store, workshops, fire and safety department, plant utilities, emergency water, process plant, laboratory, stray yard, canteen, packaging plant and the administrative block at strategic points suitable for personnel and materials transition in and out of the plant. Looking at various structures involved, plant layout design is a multidisciplinary task that needs partnership among different experts (Lira-Flores et al., 2019; Rahman et al., 2014). And according to Syeda et al. (2017), every failure has certain repercussions and effects on the surrounding region. Understanding the potential effects of these failures on the nearby facilities and their occupants is essential to designing a layout with the least amount of risk.

Conclusion

It is clear that the aforementioned objectives have been successfully achieved. Units **R-01**, **R-03**, **R-04**, **R-05** and **R-07** that are sensitive to some process variables were identified to find the optimum by analyzing the variable over an inequality constraint. Adequate controls of process variable have been carried out. Most important for an NH_3 plant are methane slippage, steam-to-carbon ratio, temperature, hydrogen-to-nitrogen ratio and S composition. All these variables were seriously emphasized in the process units and specified set points adequate for optimum operation of the units. With safety in every engineer's mind, this work encourages the adherence to safety measures that would prevent leakages as well as ensure safety of personnel and environment. Based on several available feedstock and energy sources present, different energy sources can be explored to find out the most convenient and efficient for NH_3 production, even though natural gas is one of the best alternatives for the supply of energy, currently. Ammonia can be made from many different energy sources, which could help stabilize the NH_3 price by allowing multiple technologies to compete for the lowest cost form of NH_3 production. Further research should be carried out on other NH_3 production techniques in order to reduce their cost.

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RESEARCH ARTICLE

The role of renewable energy and technological innovations toward achieving Iceland's goal of carbon neutrality by 2040

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Abstract

Iceland has set a target of becoming carbon neutral by the year 2040, and this study looks into the role that economic growth, renewable energy use, and technological innovation could play in getting them there. The Dynamic Ordinary Least Squares (DOLS) technique was used to analyze time series data from 1990 to 2021. According to the results of the DOLS estimation, a one-percentage-point increase in economic growth is associated with a 0.39% increase in CO_2 emissions. Furthermore, increasing the use of renewable energy by 1% is related to a reduction in CO_2 emissions of 1.46 percent over the long run, as indicated by the coefficient of renewable energy use being negative and statistically significant. The calculated long-run coefficient of technical innovation is negative and statistically significant, suggesting that a 1% increase in technological innovation results in a 0.02% reduction in CO_2 emissions. The empirical results show that as Iceland's economy grows, so do its CO_2 emissions, but that the country may get closer to its objective of carbon neutrality through the growing use of renewable energy and technological innovation. Alternative estimators, such as fully modified least squares (FMOLS) and canonical cointegrating regression, do not significantly affect the estimated results (CCR). Furthermore, the pairwise Granger causality test is employed to capture the causal relationship between the variables. In order for Iceland to reach its objective of carbon neutrality by 2040, this article offers policy ideas centered on a low-carbon economy, the promotion of the use of renewable energy sources, and the financing of technical progress.

Keywords: CO_2 emissions; Renewable energy; Technological innovation; Climate change; Sustainability; Carbon neutrality

Introduction

Human activities like burning fossil fuels and clearing forests contribute significantly to increasing atmospheric concentrations of GHGs, making climate change a pressing issue in the 21st century (Raihan et al., 2018; Jaafar et al., 2020; Raihan et al., 2021a; Isfat & Raihan, 2022). Consistently rising CO_2 emissions are predicted to have far-reaching implications for the global climate system, with disastrous effects for every sector of society (Raihan et al., 2019; Raihan et al., 2021b; Ali et al., 2022; Islam et al., 2022). In order to build a sustainable, progressive, and successful society in which no one is left behind, the world must work toward the goal of a climate-neutral future (Raihan et al., 2022a; Raihan & Said, 2022). Therefore, current academics have made it a priority to find ways to reduce CO_2 emissions as part of creating a green and sustainable future by considering a wide range of enabling factors, including renewable energy, technological innovation, and economic development (Raihan et al., 2022b). The United Nations has proposed Sustainable Development Goals (SDGs) for 2030 that highlight the importance of affordable and clean energy, comprehensive and sustainable economic growth, and technical innovation in the fight against climate change (SDGs 7, 8, 9, and 13).

The United Nations Framework Convention on Climate Change (UNFCCC) negotiated the Paris Pact, a multilateral environmental agreement, to enhance the global response to the risks posed by climate change within the context of sustainable development. After signing the Paris Agreement in 2016, Iceland became part of a global effort to keep global warming far below 2 degrees Celsius, with the ultimate goal of keeping it to 1.5 degrees Celsius. As part of the Paris Agreement, Iceland has committed to reducing greenhouse gas emissions by 40 percent from 1990 levels by 2030 and to achieving carbon neutrality by 2040. However, industrial activities, especially the creation of aluminum and ferrosilicon, account for the vast majority of Iceland's emissions. There are a number of other industries that contribute significantly to global warming, but transportation on the road, farming, fishing, and garbage collection all rank high. Rapid emission reduction is essential to reach climate neutrality. By taking steps to mitigate climate change, Iceland hopes to achieve multiple environmental goals at once, including better air quality, a circular economy, and biodiversity protection, as well as ensure sustainable growth and a just transition. Iceland's authorities need a better understanding of the country's net-zero emission potential if they are to strike a compromise between climate change mitigation and sustainable growth.

The question of whether or not the benefits of economic growth outweigh the costs of environmental damage informs decisions about how best to promote environmental sustainability and development (Raihan & Tuspekova, 2022a). Increases in economic growth allow for the replacement of older, more polluting technologies with newer, more environmentally friendly ones, thereby improving environmental quality (Raihan & Tuspekova, 2022b). There are a number of factors that can help decouple economic growth from environmental degradation, including shifts in output composition, the adoption of cleaner manufacturing technology, stricter environmental regulation, and a heightened public awareness of environmental issues (Raihan & Tuspekova, 2022c). As of 2022, however, Iceland's GDP per capita of USD 73,981 placed it eighth globally. At 5.8 percent, 19.7 percent, and 74.6 percent, respectively, agriculture, industry, and services all play important roles in the country's gross domestic product. Alcoa's smelter in Iceland is one of the country's main economic drivers, alongside fishing and tourism. As a result, a major issue is whether or not Iceland's growing economy is consistent with its ambition to become carbon neutral.

The importance of renewable energy has been underscored by the growing concern about global climate change and environmental sustainability (Raihan et al., 2022c; Voumik et al., 2022a). International economies are shifting toward more sustainable renewable energy sources as a result of the rapid depletion of fossil fuels and the severe environmental impacts of doing so (Raihan et al., 2022d). Renewable energy's benefits include cutting down on the use of traditional energy sources while protecting the world's economy for the long haul (Raihan et al., 2022e). Solar, water (hydropower), wind, geothermal, and biomass are the five primary sources of renewable energy (Raihan et al., 2022f). Wind, sun, and other renewable sources of energy are plentiful, clean, and safe alternatives to traditional power sources. Many people believe that renewable energy can solve the problems of energy security and pollution (Raihan et al., 2022g). The objective of reducing global emissions by half by 2050 (Raihan et al., 2022h) and of becoming carbon neutral in Iceland by 2040 both rely heavily on the use of renewable energy sources. Despite being geographically and climatically isolated, as well as having been hit hard by the 2008 financial crisis, Iceland has effectively transitioned away from fossil fuels and toward renewable sources of energy. Nearly all of Iceland's energy needs are met by hydrothermal-, geothermal-, and wind power, and the proportion of domestic renewable energy to the entire energy budget is approximately 85%, which is a far larger share than in most other countries. When compared to the usage of fossil fuels, the metal sector in Iceland is able to reduce its CO_2 emissions per ton of metal produced because of the abundance of renewable energy sources such as hydropower. The vision for sustainable energy forms the basis for Iceland's Energy Policy for 2050, which seeks to eliminate the use of fossil fuels and replace it with energy generated only from renewable sources by the year 2050. To get to carbon neutrality, Iceland needs to maximize its usage of renewable energy, hence this is an important topic for study.

At this time, technological development is the single most important factor in reducing global climate change (Raihan et al., 2022i). The consistent growth of direct environmental technology with the aim of reducing CO_2 emissions has been facilitated by the advancement of environmental legislation. The process of economic reorganization and optimization relies heavily on technological innovation (Raihan & Voumik, 2022a). To lessen the carbon dioxide (CO_2) emissions caused by industrialization, conventional economic development is shifting its focus from production to innovation. In addition, technical advancement is viewed as crucial to enhancing a nation's energy efficiency (Raihan & Voumik, 2022b). When applied to the economy, modern technologies allow for a certain level of production to be attained while requiring less energy overall. Furthermore, technological development permits the economy to shift from using nonrenewable energy sources to meeting energy needs with renewable energy sources (Raihan & Tuspekova, 2023). Technological advancements have reduced the need for fossil fuels and the resulting emissions of carbon dioxide. Almost all of Iceland's energy needs, including power and heating, are now met by renewable sources, and the country is in a prime position to take advantage of emerging technologies that will allow for the widespread electrification of transportation. Iceland's industrial structure may be modernized with the help of technological advancements, and this would be an excellent catalyst for the country's economic progress. To boost economic growth and reach carbon neutrality, studying the impact of technological innovation on environmental sustainability is essential from a theoretical and practical standpoint.

Getting to a climate-neutral society will need the concerted efforts of numerous groups working in tandem. This intricacy presents a problem for the government, which must begin with defining who is responsible for what and how at the federal, state, and municipal levels, as well as among commercial and public actors and individual individuals. Finding innovative ways to collaborate between different tiers of government and the Government and civil society actors will also be a component of this. Considering that Iceland wants to be carbon neutral by 2040, it is crucial to analyze how policy, instruments, and measures promote a low-emission pathway up to 2050. A clear explanation of the most important parameters is necessary before a target of climate neutrality can be set. For practically any country, planning the strategy to achieve the goal of net zero emissions within a few decades is an enormous task that will call for bold and effective steps. There must be openness and clarity about the goal's associated parameters. Even while studies into the possibility of emission reduction factors using econometric methodologies has become a hot topic in recent years, there has been surprisingly little investigation of this question in Iceland. This study tries to fill this knowledge vacuum by using the dynamic ordinary least squares (OLS) method to examine how GDP growth, renewable energy consumption, and technological innovation affect CO_2 emissions in Iceland.

This research is important because it provides insights that may be used in a variety of ways to both existing literature and ongoing policy debates in Iceland. To begin with, the novel findings from the in-depth econometric analysis of the relationship between CO_2 emissions and emission reduction factors in the context of Iceland fill a void in the prior academic literature. New to this study is an analysis of how the adoption of renewable energy sources and technology advancements can affect Iceland's carbon footprint. Second, our study sheds light on the often-overlooked but crucial function of patent applications in emission reduction. And third, the study included the most recent and comprehensive data available over a 32-year time frame (1990–2021). To ensure the reliability of the findings, multiple diagnostic tests and cointegration models (including the ADF, DF-GLS, and P-P tests) were used. Fifth, the Granger causality test was used to determine the direction of the relationship between the variables. For Iceland to reach its objective of carbon neutrality by 2040, the findings of this study will give policymakers more complete and relevant information for formulating successful policies in the areas of a low-carbon economy, boosting renewable energy consumption, and supporting technological innovation. Furthermore, the results of this study can be applied to the review and development of environmental policies to help get Iceland ready for a 1.5°C world by bolstering policy and action plan to lessen the effects of climate change and ensure sustainable development. The findings from this study may also be useful for other developing nations as they seek to fortify their own climate change mitigation and adaptation plans.

The rest of the article is structured as follows. The Introduction is followed by the section Literature Review, where relevant research studies have been discussed. The third section is the Methodology section, followed by the Results and Discussion section. Subsequently, the last section presents the Conclusion, policy recommendations, limitations of the study, and future research directions.

Literature Review

Numerous studies have been performed over the past several years to determine how and to what degree renewable energy can cut down on carbon dioxide emissions. A number of economic analyses have concluded that expanding the usage of renewable energy sources would lead to lower levels of carbon dioxide emissions. Moreover, several empirical studies have demonstrated the link between expanding economies and rising CO_2 emissions. Multiple studies were taken into account, from a number of different nations, considering a number of different aspects and using a number of different approaches. Chen et al. (2019) looked at China's CO_2 emissions, economic growth, and use of renewable energy sources between 1980 and 2014 and found that the latter two were inversely associated with the former. Using a sophisticated panel quantile regression model, Azam et al. (2022) found a positive correlation between GDP growth and CO_2 emissions in the top five emitter countries for the years 1995–2017, and a negative correlation between renewable energy and CO_2 emissions in these same countries. Using data from 1990 to 2018, Raihan and Tuspekova (2022a) found that economic growth was positively related to CO_2 emissions, whereas the use of renewable energy was negatively related to emissions. Using data from 1990 to 2019, Raihan and Tuspekova (2022c) discovered that the usage of renewable energy was inversely related to CO_2 emissions in Nepal, while the use of fossil fuels was positively related to emissions.

Furthermore, Liu et al. (2017) used time data from 1970-2013 to find a negative correlation between CO_2 emissions and the utilization of renewable energy sources in Indonesia, Malaysia, the Philippines, and Thailand. Using data from 1990 to 2019, Raihan and Tuspekova (2022d) discovered that economic expansion positively affected CO_2 emissions in Brazil, whereas the use of renewable energy negatively affected CO_2 emissions. With data from 1990 to 2020, Raihan and Tuspekova (2022e) found that economic expansion positively affected CO_2 emissions in Turkey, while renewable energy negatively affected CO_2 emissions. Data from 1990-2019 was also used by Raihan and Tuspekova (2022f) to show that economic expansion positively affected CO_2 emissions in Mexico, whereas the use of renewable energy negatively affected CO_2 emissions in the country. Using data from 1970 to 2013, Raihan et al. (2022h) found that in Argentina, increasing economic activity was associated with higher CO_2 emissions, whereas increasing reliance on renewable energy sources was associated with lower emissions.

In addition, increasing R&D spending can improve economic production efficiency and resource consumption efficiency, hence the connection between technical innovation and CO_2 emissions has been studied extensively in recent years. We anticipate that technological progress will have a significant impact on cleaning up the environment. Many countries have successfully decreased their CO_2 emissions and enhanced their environmental performance thanks to new technologies and environmental protection measures. The favorable impact that technology advancements might have on carbon dioxide emissions has been the subject of a lot of prior research. Because patents safeguard business interests and intellectual property, they are favored by most academics as a proxy for technological innovation in the service of solving environmental issues. Green technology innovation is widely regarded as having positive effects on the environment, and Chen and Lee (2020) argue that this is especially true of technological advancements in high-income countries, where they can be reduced effectively. There are several empirical studies demonstrating that technical progress helps lower carbon dioxide emissions. Increasing the efficiency of technological innovation in China has a profoundly beneficial effect on environmental performance, claim Shahbaz et al. (2020). According to Rahman et al. (2019), if foreign companies use clean technology, it could improve environmental quality in Pakistan by reducing carbon emissions. To better the environment, technological advancements have been shown to decrease CO_2 emissions in 24 European countries (Ahmed et al., 2016).

In addition, using data from 1990 to 2019, Raihan et al. (2022b) found that in Malaysia, increasing economic activity was positively correlated with CO_2 emissions, whereas increasing usage of renewable energy sources and technological advancement was negatively correlated with CO_2 production. With data from 1996-2018, Raihan and Tuspekova (2022b) found that economic expansion positively affected CO_2 emissions in Kazakhstan, but the usage of renewable energy and technical innovation negatively affected CO_2 emissions. Using data from 1990 to 2020, Raihan and Voumik (2022a) found that economic expansion positively affected CO_2 emissions in India, while the usage of renewable energy and technical innovation negatively affected CO_2 emissions in India. Using data from 1990 to 2020, Raihan and Voumik (2022b) found that economic expansion positively affected CO_2 emissions in China, while the usage of renewable energy and technical innovation negatively affected CO_2 emissions in China. Using data from 1990-2019, Raihan et al. (2022f) found that economic expansion increased CO_2 emissions in Bangladesh, whereas the usage of renewable energy and technological advancement decreased them. Using data from 1990 to 2020, Raihan et al. (2022g) also demonstrated the beneficial benefits of economic growth on CO_2 emissions, as well as the detrimental consequences of renewable energy consumption and technical advancement. As it is already generally understood that technological innovations play a substantial role in reducing emissions while sustaining economic growth, any greater understanding of the process of technological innovation is likely to increase our knowledge of mitigation possibilities.

Despite this encouraging trend, the entire potential of renewable energy use and technical innovation is yet unclear, as are the methods of knowledge acquisition. Therefore, the current study aims to address the vacuum in the literature by combining multiple econometric methodologies to investigate the potential of economic growth, renewable energy use, and technical breakthroughs to help Iceland reach its objective of carbon neutrality.

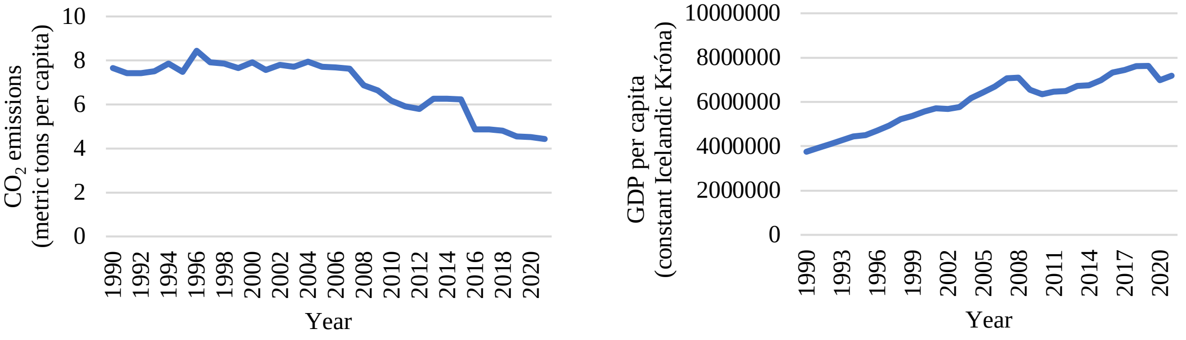
Methodology

Data

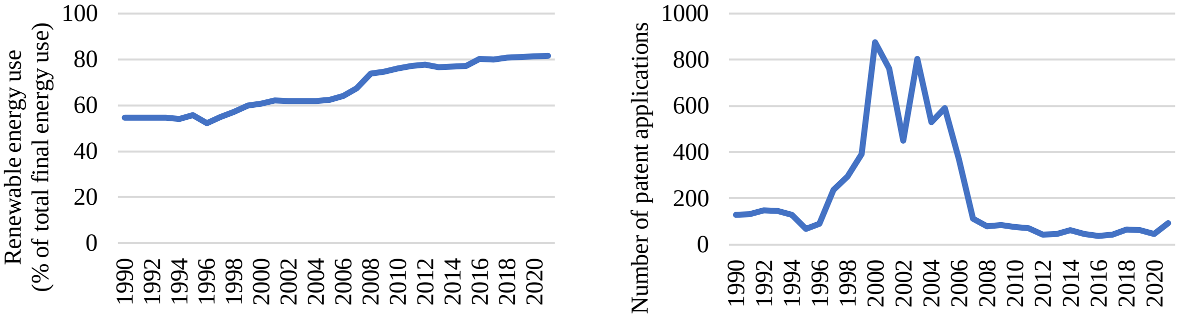
By applying the DOLS method of cointegration developed by Stock and Watson (1993), this study offers an empirical examination of the dynamic effects of economic development, renewable energy utilization, and technical advancement on CO_2 emissions in Iceland. This study's econometric analysis made use of the most up-to-date Icelandic time series data, which stretched from 1990 to 2021. The numbers were taken from the World Development Indicator (WDI) database (World Bank, 2022). In this study, carbon dioxide emissions served as the dependent variable, while economic expansion, renewable energy use, and technological progress served as the explanatory variables. Furthermore, it should be mentioned that technical innovation refers to the interest in finding new technology shown by a country's industrial and commercial entities, which may be quantified using a metric like the number of patents. Since patents are the formalized form of technology, patenting activities can stand in for innovation in that field. An increase in patent applications is a sign that businesses and individuals want to adopt cutting-edge innovations. As a result, the total number of patent applications has been used as a stand-in for technological progress (both domestic and foreign). In addition, a logarithmic transformation is applied to the variables to guarantee a normal distribution. Table 1 displays the variables, their logarithmic representations, the units of measurement, and the researchers that collected the data. Moreover, Figure 1 displays the annual trends of the research variable.

Table 1. Data sources, units of measure, and logarithms of the variables

Variables	Description	Logarithmic forms	Units	Sources
CO_2	CO_2 emissions	LCO2	Metric tons per capita	WDI
GDP	Economic growth	LGDP	GDP per capita (constant Icelandic Króna)	WDI
RNE	Renewable energy use	LRNE	% of total final energy use	WDI
TI	Technological innovation	LTI	Number of patent applications	WDI



(a) CO_2 emissions (b) Economic growth



(c) Renewable energy (d) Technological innovation

Figure 1. Annual trends of the study variables

Theoretical framework

In this research, we use the framework of a Cobb-Douglas production function to analyze the hypothesis (Cobb & Douglas, 1928). This research topic uses standard production economics to assess how GDP growth, renewable energy adoption, and technical progress have affected CO_2 emissions in Iceland. If we assume a constant rate of return and use a typical Cobb-Douglas production function, we can derive the aggregate output function as follows:

$$Y_t = f\ (K_t, L_t) \tag{1}$$

where Y_t is the GDP at time t, K_t is capital at time t, and L_t is effective labor at time t

There is a theoretical link between CO_2 emissions and financial success. Given the widespread belief that emissions of carbon dioxide (CO_2) are caused by human economic activity, we can express the CO_2 emission function as:

$$CO_{2t} = f\ (GDP_t) \tag{2}$$

where CO_{2t} is the CO_2 emissions at time t

Moreover, rapid economic expansion is associated with increased energy consumption in the manufacturing process (Raihan, 2023a), while increasing the amount of renewable energy in the overall final energy use helps to achieve environmental sustainability by lowering carbon emissions from fossil fuel energy sources (Raihan, 2023b). Therefore, the goal of this research is to provide an estimate of how much renewable energy utilization affects carbon dioxide emissions. As a result, Eq. (2) may be rewritten as:

$$CO_{2t} = f\ (GDP_t;\ RNE_t) \tag{3}$$

where RNE_t is the renewable energy use at time t

This study takes into account technological innovation in the model as a result of the discussion in the introduction and literature review sections, which show that technological innovation can have multiple effects on CO_2 emissions. Technological advancement is also important since it increases factor productivity and guarantees energy efficiency, both of which contribute to economic growth. In order to understand the relationship between CO_2 emissions, economic growth, renewable energy consumption, and technological innovation, the current study employed the following economic functions:

$$CO_{2t} = f\ (GDP_t;\ RNE_t;\ TI_t) \tag{4}$$

where TI_t is the number of patent applications at time t

Econometric model

Equation (5) depicts the empirical model:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 TI_t \tag{5}$$

Equation (5) is further expanded as the econometric model in the following form:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 TI_t + \varepsilon_t \tag{6}$$

where τ_0 and ε_t stand for intercept and error term, respectively. In addition, τ_1, τ_2, and τ_3 denote the coefficients.

Moreover, Equation (7) shows the logarithmic arrangement of Equation (6):

$$LCO2_t = \tau_0 + \tau_1 LGDP_t + \tau_2 LRNE_t + \tau_3 LTI_t + \varepsilon_t \tag{7}$$

Figure 2 is a flowchart of the analytic methods used to investigate the impact of Iceland's expanding economy, increasing reliance on renewable energy, and rapid technological advancement on the country's carbon footprint.

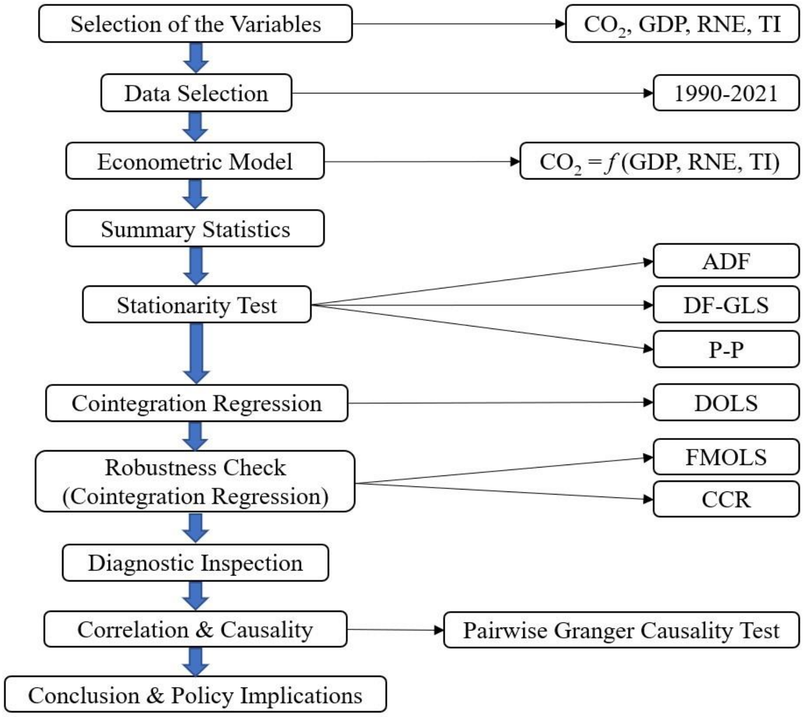


Figure 2. Flow chart of the analytical techniques employed in the study

Stationarity techniques for data

Using a unit root test is essential for preventing erroneous regression. By differentiating the variables in the regression and using stationary processes to estimate the equation of interest, this method ensures that the variables are, in fact, stationary (Raihan & Tuspekova, 2022g). Before investigating cointegration between variables, the empirical literature recognizes the requirement to define the sequence of integration. Since the power of unit root testing varies with sample size, several studies recommend using multiple tests to determine the best sequence for series integration (Raihan & Tuspekova, 2022h; Raihan, 2023c). We employed the Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller (1979), the Dickey-Fuller generalized least squares (DF-GLS) test proposed by Elliott et al. (1992), and the Phillips-Perron (P-P) test proposed by Phillips and Perron (1996) to identify the autoregressive unit root (1988). To guarantee that no variables in this study surpassed the order of integration and to provide more evidence for the superiority of the DOLS technique over conventional cointegration methods, the unit root test was employed.

DOLS cointegration regression

The time series data in this research was analyzed using DOLS, an extended equation of ordinary least squares estimation. The DOLS cointegration test uses explanatory factors together with leads and lags of their initial difference terms to regulate endogeneity and calculate standard deviations using a covariance matrix of errors that is resistant to serial correlation (Raihan & Tuspekova, 2022i). The orthogonalization of the error term is shown by the inclusion of the leading and trailing terms of the individual ones. Using the DOLS estimator's standard deviations as a test for statistical significance is a safe bet because they follow a normal asymptotic distribution. The DOLS method is useful for integrating cointegrated outlines with factors that integrate in a different order, as it estimates the dependent variable based on the explanatory variables in levels, leads, and lags (Raihan & Tuspekova, 2022j). The mixed-order integration of individual variables in the cointegrated outline is the primary benefit of the DOLS estimation. Some of the other variables in the regression were also I(1) variables with leads (p) and lags (-p) of the initial difference, while others were I(0) variables with a constant term, as in DOLS estimation (Begum et al., 2020). This estimate eliminates problems with small sample bias, endogeneity, and autocorrelation by summing the leads and lags among explanatory factors (Raihan et al., 2023a). It is only after establishing that the variables are cointegrated that the study moves on to estimating the long-run coefficient with DOLS (using Equation 8).

$$\begin{aligned}\Delta \mathrm{LCO2}_t = {} & \tau_0 + \tau_1 \mathrm{LCO2}_{t-1} + \tau_2 \mathrm{LGDP}_{t-1} + \tau_3 \mathrm{LRNE}_{t-1} \\ & + \tau_4 \mathrm{LTI}_{t-1} + \sum_{i=1}^{q} \gamma_1 \,\Delta \mathrm{LCO2}_{t-i} \\ & + \sum_{i=1}^{q} \gamma_2 \,\Delta \mathrm{LGDP}_{t-i} + \sum_{i=1}^{q} \gamma_3 \,\Delta \mathrm{LRNE}_{t-i} \\ & + \sum_{i=1}^{q} \gamma_4 \,\Delta \mathrm{LTI}_{t-i} + \varepsilon_t \end{aligned} \tag{8}$$

where Δ is the first difference operator and q is the optimum lag length in Equation (8).

Robustness check

In order to ensure the validity of the DOLS results, we used the fully modified OLS (FMOLS) and Canonical Cointegrating Regression (CCR). Hansen and Phillips (1990) created the FMOLS regression to integrate the most accurate estimates of cointegration. The FMOLS method is a modification of least squares that allows for endogeneity in the independent variables and serial correlation effects due to cointegration. The FMOLS method aids with spurious regressions by employing conventional regression techniques (OLS) for nonstationary (unit root) data. The CCR method, which involves transforming data with only the stationary component of a cointegrating model, was also pioneered by Park (1992). A cointegrating link from the cointegrating model will remain unchanged after such data processing. The CCR transformation eliminates the zero-frequency dependence of the error term on the regressors in a cointegrating model. The CCR method yields asymptotically efficient estimators and asymptotic chi-square tests that are devoid of nuisance parameters. Asymptotic coherence can be established with the help of FMOLS and CCR techniques by examining the impact of serial correlation (Raihan & Tuspekova, 2022k). Consequently, the FMOLS and CCR estimators are utilized to determine the long-term elasticity, as demonstrated by Equation (8).

Pairwise Granger causality

The goal of this study is to identify the relationships between the variables that lead to the observed effects. Therefore, in order to determine whether or not there is a causative relationship between the variables, the paired linear Granger-causality test introduced by Granger (1969) was implemented in this study. The present study adopts the "statistical notion of causation based on prediction" of Granger causality because of its many benefits over alternative time-series evaluation methods. To say that one time series Y "Granger-causes" another is to say that it aids in the forecasting of another time series X. The time series for these two variables has a length of T, where X_t and Y_t (t=1,2,...,T) are the values for X and Y at time t. Following are some equations for applying a bivariate autoregressive model to the Xt and Yt models:

$$X_t = \beta_1 + \sum_{i=1}^{n} \alpha_i Y_{t-i} + \sum_{i=1}^{n} \mu_i X_{t-1} + e_t \tag{9}$$

$$Y_t = \beta_2 + \sum_{i=1}^{n} \Omega_i Y_{t-1} + \sum_{i=1}^{n} \infty_i X_{t-i} + u_t \tag{10}$$

where n signifies the number of lags, as stipulated by the data measures β_1, β_2, α_i, Ω_i, μ_i, and ∞_i as factors for assessment; and e_t and u_t are residual terms.

Estimation of the coefficients can be done using the ordinary least squares method, and Granger causality between X and Y can be determined using F tests.

Results and Discussion

Summary statistics

Table 2 displays the statistical values of many normality tests (skewness, probability, kurtosis, and Jarque-Bera) applied to the outcomes of the summary measures between variables. Icelandic time series data for each variable spans the years 1990 through 2021 and features 32 observations. Negative skewness values indicate that all of the variables are normally distributed. Researchers also used kurtosis to determine whether or not the series they were studying deviated significantly from a normal distribution. All empirical series are shown to be platykurtic, with values below 3. All the parameters are normal, as shown by the tiny values of the Jarque-Bera probability.

Table 2. Summary statistics of the variables

Variables	LCO2	LGDP	LRNE	LTI
Mean	1.897761	15.58626	4.195806	4.911573
Median	2.008804	15.67194	4.146941	4.641562
Maximum	2.133136	15.84703	4.401940	6.775366
Minimum	1.488630	15.13740	3.956101	3.637586
Std. Dev.	0.199138	0.210312	0.157950	0.975610
Skewness	-0.917764	-0.687887	-0.021779	0.578600
Kurtosis	2.432830	2.253088	1.396069	2.035290
Jarque-Bera	2.921124	2.267509	2.432657	2.026372
Probability	0.185387	0.195195	0.179725	0.220207
Observations	32	32	32	32

Results of unit root tests

To ensure that no variables had an order of integration I higher than the others, we used the unit root test to support the use of the DOLS estimator rather than cointegration (1). We employed trend-and-constants-based ADF and DF-GLS and P-P methods to isolate the autoregressive unit root. The outcomes of the ADF, DF-GLS and P-P tests for locating the unit root are shown in Table 3. All three unit root tests show that the variables were not level-stationary, but did become stationary once the first difference was taken. Therefore, the unit root results suggest that the variables share a first-difference order of integration. This means that there is no possibility of a deceptive regression analysis because all of the variables included in the empirical investigations tend toward their true values.

Table 3. The results of unit root tests

Logarithmic form of the variables		LCO2	LGDP	LRNE	LTI
ADF	Log levels	0.315282	-2.198261	-0.351326	-1.224113
	Log first difference	-6.210401***	-3.725762***	-4.767828***	-4.443520***
DF-GLS	Log levels	0.322991	-0.394066	-0.043295	-1.250108
	Log first difference	-6.266548***	-3.628563***	-4.738730***	-4.465485***
P-P	Log levels	0.989018	-2.604318	-0.351326	-1.402678
	Log first difference	-6.184393***	-3.725762***	-4.792888***	-4.390266***

*** denotes significance at the 1% level

DOLS outcomes

The DOLS estimation results are shown in Table 4. The estimated long-run coefficient of LGDP is positive and statistically significant at the 5% level, indicating that a 1% increase in economic growth would result in a 0.39% increase in CO_2 emissions when all other variables are held constant. This research shows that economic expansion causes environmental deterioration over time. The positive correlation between GDP and CO_2 emissions is substantiated by previous studies (Chen et al., 2019; Raihan et al., 2022h; Azam et al., 2022; Raihan and Tuspekova, 2022a; Liu et al., 2017; Raihan and Voumik, 2022a; Raihan et al., 2022b; Raihan and Tuspekova, 2022e; Raihan, 2023d). Emissions have increased as industrialization has led to more energy use, infrastructural development, and economic capitalization, all of which have had a positive effect on investments and business output. When the economy expands, pollution levels tend to rise alongside it. It causes greater pollution, waste, and environmental deterioration as more societal demands are met through consumption and development activities (Voumik et al., 2022b). As a result, economic activities appear to be appropriate for environmental protection and development, rather than posing a threat to long-term environmental quality. As a result, the ability to attain carbon neutrality may be at risk unless the economy makes a massive transition to using low-carbon technology for manufacturing products and services. Consequently, in order to achieve carbon neutrality in Iceland, effective policies and ways to reduce dependency on fossil fuel supply, energy intensity, and CO_2 emissions are required.

Table 4. The outcomes of DOLS: dependent variable LCO2

Variables	Coefficient	Standard Error	t-Statistic	P-value
LGDP	0.388981**	0.162696	2.390848	0.0238
LRNE	-1.458025***	0.274945	-5.302967	0.0000
LTI	-0.025821**	0.015863	-1.627737	0.0148
C	1.825774	1.451903	1.257504	0.2190
R^2	0.914452			
Adjusted R^2	0.907823			

*** and ** signify significance at the 1% and 5% levels, respectively

When looking at long-term effects, however, the estimated coefficient of renewable energy use is negative and statistically significant at the 1% level, suggesting that increasing the use of renewable energy by 1% is linked to a reduction in CO_2 emissions of 1.46 percent. This demonstrates the possibility of reducing emissions by increasing the usage of renewable energy sources in Iceland. Our data suggest that the use of renewable energy sources is crucial for Iceland to reach carbon neutrality. The results of this study are in line with those of numerous other studies, including those by Chen et al. (2019), Raihan et al. (2022h), Azam et al. (2022), Raihan and Tuspekova (2022a), Liu et al. (2017), Raihan and Voumik (2022a), Raihan et al. (2022b), Raihan and Tuspekova (2022b), and Raihan et al. (2023b) Using renewable sources for energy generation is crucial to both sustainable development and climate change mitigation in the face of the looming threat of climate change. Renewable energy provides substantial economic benefits, such as greater energy availability, improved energy security, and the use of local renewable resources, in addition to reducing carbon emissions.

We also investigate how technological progress can help Iceland reach carbon neutrality. At the 5% significance level, the predicted long-run coefficient of technological innovation is negative, meaning that for every 1% increase in technical innovation, CO_2 emissions decrease by 0.02%. The empirical result suggests that a rise in patent applications may result in lower levels of carbon dioxide emissions. This suggests that the adoption of green technologies in Iceland's industrial sector may contribute to the country's efforts to improve environmental quality by achieving its target of zero emissions. Our findings are consistent with those of other researchers who have found that technological advancements aid in environmental sustainability, including Chen and Lee (2020), Shahbaz et al. (2020), Ahmed et al., (2016), Raihan and Voumik (2022a), Raihan et al. (2022b), Raihan and Tuspekova (2022b), and Raihan et al. (2023c). With the help of a green economy and green technologies, Iceland can reach its goal of becoming a carbon-neutral country by 2040. The debate over the part that patent applications should play in reducing climate change is heating up as we enter an era in which there is a greater awareness of the need for environmental sustainability. Green technology patents guarantee that the environment will always be preserved for future generations even as they are used to advance the field.

It is also worth noting that the theoretical and practical indications of the estimated coefficients are consistent. It appears that the computed regression model fits the data pretty well, with R^2 and modified R^2 values of 0.9144 and 0.9078, respectively. This suggests that the changes in the independent variables may explain 90% of the variation in the dependent variable.

Robustness check

To ensure that DOLS estimation was consistent, we used the FMOLS and CCR estimators. Tables 5 and 6 display the model's estimated FMOLS and CCR values, respectively. The results of the FMOLS and CCR estimations show how reliable the DOLS estimation is. The positive coefficient of economic growth was validated at a 5% level of significance by both the FMOLS and CCR estimation results. Moreover, the negative coefficient of renewable energy use was confirmed at the 1% level of significance in both FMOLS and CCR estimate results. In addition, FMOLS and CCR estimation results corroborate the negative relationship between technological progress and carbon dioxide emissions at the 5% significant level. Additionally, the goodness of fit is reflected in the estimated R2 and modified R2 values from FMOLS and CCR estimates. Thus, it can be concluded that CO_2 emissions rise as the Icelandic economy expands, while progress in renewable energy and technology allows the country to become carbon neutral.

Table 5. The results of FMOLS: dependent variable LCO2

Variables	Coefficient	Standard Error	t-Statistic	P-value
LGDP	0.378047**	0.289937	1.303895	0.0233
LRNE	-1.517329***	0.468830	-3.236418	0.0003
LTI	-0.027211**	0.034247	-0.794547	0.0348
C	2.228276	2.714170	0.820979	0.1488
R^2	0.919242			
Adjusted R^2	0.906533			

*** and ** signify significance at the 1% and 5% levels, respectively

Table 6. The results of CCR: dependent variable LCO2

Variables	Coefficient	Standard Error	t-Statistic	P-value
LGDP	0.371311**	0.322907	1.149902	0.0263
LRNE	-1.499439***	0.478408	-3.134225	0.0001
LTI	-0.028437**	0.034894	-0.814965	0.0422
C	2.253500	3.187279	0.707029	0.1856
R^2	0.912023			
Adjusted R^2	0.900785			

*** and ** signify significance at the 1% and 5% levels, respectively

Diagnostic inspection

We ran tests for normality, heteroscedasticity, and serial correlation to make sure the cointegration assessment was accurate. The outcomes of the diagnostic procedures are summarized in Table 7. There is no autocorrelation or heteroscedasticity in the model, and the data are normally distributed. Moreover, we used the CUSUM and CUSUMQ tests to examine the model's robustness to recursive changes. In Figure 3, we see the CUSUM and CUSUMQ plots at the 5% level of significance. The blue lines show the residual values, while the red lines show the confidence intervals. The estimated values of the examined residuals are consistent with the confidence intervals, indicating that the model is stable at the 5% level of significance.

Table 7. The results of diagnostic tests

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera test	2.022942	0.3637	Residuals are normally distributed
Breusch-Godfrey LM test	1.864723	0.3214	No serial correlation exits
Breusch-Pagan-Godfrey test	1.534236	0.1897	No heteroscedasticity exists

Results of the pairwise Granger causality

The existence of Granger causality is established using the F-statistic, which measures the strength of the correlation between the variables. Table 8 displays an overview of the pairwise Granger causality. The statistical significance of the findings of the pairwise Granger causality tests leads to the rejection of the null hypothesis, indicating that there is unidirectional causality from LGDP to LCO2, LCO2 to LRNE, LGDP to LRNE, LGDP to TI, and LTI to LRNE. This means that in Iceland, economic growth leads to increased CO_2 emissions, which in turn leads to increased use of renewable energy sources, which in turn leads to increased economic growth, which in turn leads to increased use of renewable energy sources, etc. The results show that the usage of renewable energy sources becomes more crucial when CO_2 emissions rise in tandem with economic development. More evidence is that a thriving economy may spur the development of cutting-edge renewable energy sources. As a result of the resources made available by a flourishing economy, research into and development of renewable energy technology and infrastructure can expand. To meet growing energy needs and improve efficiency, technological advancements are aiding the shift away from fossil fuels and toward renewable energy. In contrast, the results of a pairwise Granger causality test show that advancements in technology are not a direct result of increases in carbon dioxide emissions. In Figure 4, we see the relationships between the studied factors.

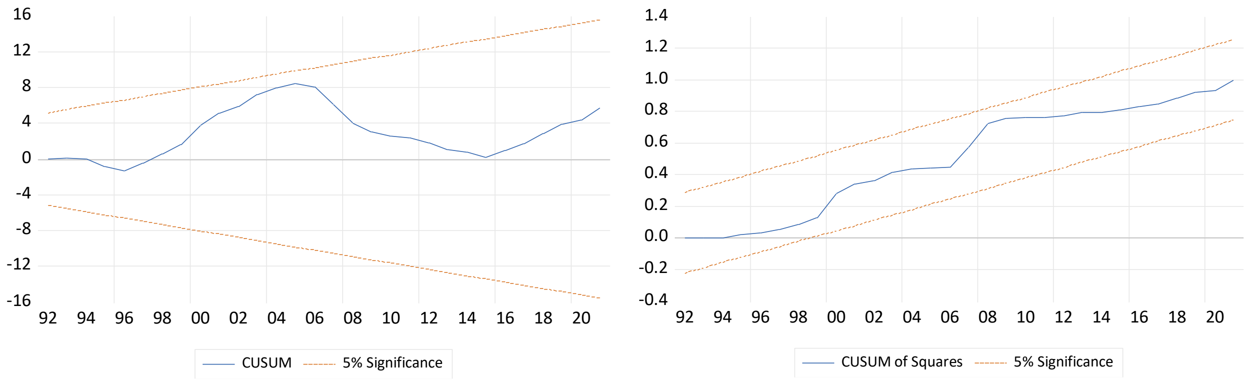


Figure 3. The plots of CUSUM and CUSUMQ tests

Table 8. The results of the pairwise Granger causality test

Causality direction	F-statistic	Decision
LGDP → LCO2	3.72452**	√
LCO2 → LGDP	1.72349	×
LRNE → LCO2	2.18945	×
LCO2 → LRNE	3.82529*	√
LTI → LCO2	1.82365	×
LCO2 → LTI	2.41381	×
LRNE → LGDP	0.87423	×
LGDP → LRNE	7.80137***	√
LTI → LGDP	0.20184	×
LGDP → LTI	3.19236**	√
LTI → LRNE	3.98125**	√
LRNE → LTI	0.49813	×

***, **, and * denote significance at the 1%, 5%, and 10% levels

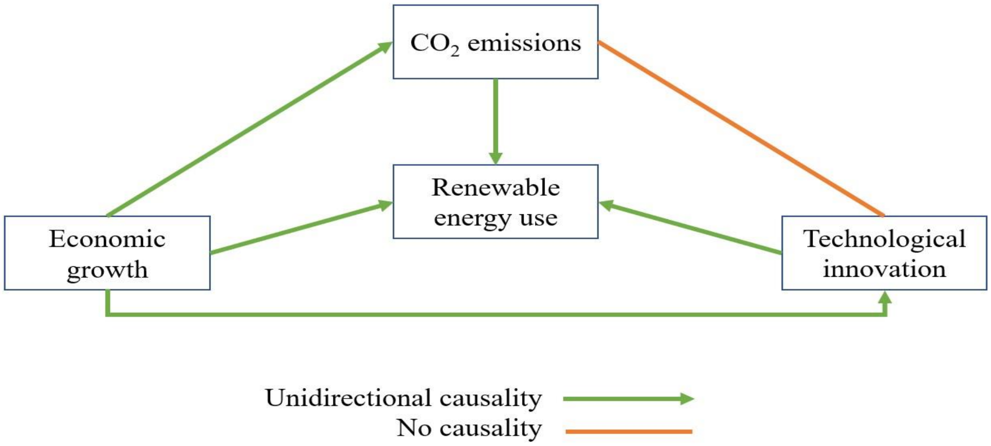


Figure 4. Granger causality between the examined variables

Our research also shows that there is a one-way causality between economic growth and technical innovation, with the former serving to spur the latter. When a nation's GDP grows, it has more disposable income to put toward R&D and the introduction of cutting-edge technologies. Increases in technological efficacy lead to less waste and pollution as a result of reduced resource use and product by-products. The environmental quality is predicted to increase, for instance, if more money is invested in research and development. Our research also shows that the adoption of renewable energy is a direct result of economic development and technological progress. As the economy expands, new technologies will enable the widespread adoption of renewable energy. Instead, thanks to the government's extensive renewable energy promotion strategy, the renewable energy industry is now an important economic sector that greatly contributes to the country's socioeconomic and long-term progress. Jobs, lower prices, and a less polluted environment are just a few of the ways in which the expansion of renewable energy has improved people's quality of life and helped to improve the world overall. In order for Iceland to become carbon neutral, the economy must continue to grow, as this will provide the funds necessary to investigate and develop renewable energy technologies and infrastructure.

The growth of environmentally friendly industries and the electrification of transportation are both bolstered by the responsible use of renewable energy sources. Low-carbon businesses like data centers and high-tech horticulture are vital to Iceland's economy, which once relied on aluminum smelters. Iceland's economy still relies heavily on the fishing and tourist industries. Using technological solutions, Iceland has achieved a carbon footprint of zero. In this energy infrastructure, renewable resources are used extensively. Electricity, hydrogen, and synfuels power land transportation, while the aviation and maritime industries have only partially adopted low-carbon alternatives. However, hydrogen and synfuels have replaced fossil fuels in Iceland's fishing sector. Capturing emissions from energy-intensive sectors and either mineralizing them or using them to create synfuels. The number of farm animals has decreased, and manure management has improved. In order to become carbon neutral by 2040, all of Iceland's organic waste is composted and/or gasified.

Conclusion and Policy Implications

This research looks into how carbon neutrality in Iceland can be accomplished by factors like economic development, renewable energy adoption, and technical advancement. The DOLS technique was used on time series data that extended from 1990 to 2021. In this research, we used the ADF, DF-GLS, and P-P unit root tests to determine the order of integration of the series. According to the results of the DOLS estimation, a one-percentage-point increase in economic growth is associated with a 0.39% increase in CO_2 emissions. Furthermore, increasing the use of renewable energy by 1% is related to a reduction in CO_2 emissions of 1.46 percent over the long run, as indicated by the coefficient of renewable energy use being negative and statistically significant. The calculated long-run coefficient of technical innovation is negative and statistically significant, suggesting that a 1% increase in technological innovation results in a 0.02% reduction in CO_2 emissions. Estimates hold up well when compared with both the FMOLS and CCR methods. The paired Granger causality test was also used to capture the causal relationship between the variables. Our research provides fresh insight into how the adoption of renewable energy sources and cutting-edge technological advancements in Iceland has contributed to the country's progress toward carbon neutrality. Recommendations for policy were made in this article to promote sustainable development through the introduction of robust regulatory policy tools targeted at achieving carbon neutrality.

It will take new methods and procedures to get to net zero emissions, which is not an easy aim to achieve. An all-out effort, substantial investment, and careful planning are needed to make the leap to a climate-neutral civilization. In order to keep the political debate on the future's direction going strong, it is crucial to keep gathering facts and best practices. To reach carbon neutrality, all emissions must be reduced, and the many causes and potential remedies must be taken into account. For this reason, it's possible that a variety of sector-specific policies and initiatives will need to be implemented simultaneously in order to move forward. To reach carbon neutrality, the strategy must be adaptable and leave room for novel, creative ideas. Government actors, industrial partners, non-governmental organizations, and local municipalities must all work together and actively participate in the development and systematic reevaluation of a viable strategy for a climate-neutral Iceland by no later than 2040. To achieve a fair transition to a circular, competitive, climate-neutral future, the public must be involved in its development. Many local governments, businesses, and non-profits, as well as national organizations, have taken action to address climate change. Iceland's greenhouse gas emissions are predicted to decrease as a result of these measures. Since government effort alone won't be enough to combat climate change, it's crucial to back such projects.

Our study suggests that the Icelandic government aid markets by constructing a strong legislative framework that creates lasting value for carbon neutrality and consistently encourages innovative technologies that result in a less carbon-intensive economy. Iceland's government is considering expanding its use of carbon capture and storage systems with the goal of becoming carbon neutral. Policymakers should also support and promote renewable energy businesses and innovations. These steps will aid the transition to a low-carbon economy by replacing more traditional energy sources that produce a lot of carbon dioxide. The need to diversify the economy was made clear by the decline in international tourism and travel caused by the pandemic. If emission reductions are to be a priority, Iceland will need to strengthen its ability to withstand shocks and find alternative ways to boost productivity and employment. More entrepreneurial vigor would be helpful in diversifying the economy and starting along the low-carbon route. The economic recovery and productivity growth in the medium term may be slowed by Iceland's high barriers to entry in goods and service markets, which are among the highest in the OECD. Weakening competitiveness and slowing productivity are excessive occupational licensing in the building industry and heavy administrative costs in the tourism industry. It would be easier for the government to reallocate funds if regulations were simplified across the board to lower barriers to both domestic and international competition.

In order to achieve the goals of a future without fossil fuels, in which all energy production comes from the renewable origin by 2050, the government could create and implement effective policies to support investment in new renewable energy technology. As a corollary, new technologies will need to be created through research and patent applications in order to reach the carbon neutrality goal. The creation of energy-saving technology is a part of this effort and will likely play a major role in any future stability policy. Hybrid vehicles are one example of how modern technology can reduce energy use without compromising performance. The government may raise funding for enterprises conducting technological innovation research on energy conservation and emission reduction in order to foster the development of low-carbon technology. The Icelandic government is considering increasing its cooperation with academic institutions in an effort to promote technical innovation, especially in the field of green technology. Green technology, such as renewable energy sources, energy storage, management, recycling and waste technologies, and GHG disposal, can all contribute to a more sustainable way of life. Innovative green technology utilization in the industry may have positive effects on all three of these fronts. In addition, the government should encourage the commercialization of patents and the development of novel energy sources and environmental protection measures.

Although our approach has significant weaknesses, which may be addressed in future studies, our current study did produce substantial empirical findings in the case of Iceland. The inaccessibility of data beyond the study period severely restricts the usefulness of the econometric methods we employed. This research, however, looks at the interplay between Iceland's expanding economy, renewable energy sources, technological progress, and carbon dioxide emissions. Increasing forest cover, recycling items, decreasing water and electricity consumption, switching to organic food, etc. are all potential factors in lowering emissions that could be investigated in future research. Degradation of the environment due to GHG emissions were also measured using CO_2 in this study. Consumption-based carbon emissions, along with other emission indicators such as nitrous oxide, sulfur dioxide, methane, and other transient climate pressures, could be used as proxies for environmental deterioration in more studies. CO_2 emissions are not the main contributor to environmental degradation, but they are used as a proxy for pollution in this study. Water and soil contamination are two forms of environmental pollution that could be studied in greater depth in future studies of Iceland.

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RESEARCH ARTICLE

Ecological Footprint of Energy Consumption In Ijebu Ode, Nigeria

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Abstract

Notwithstanding overwhelming evidence that shows how unsustainable energy consumption contributes to our already rising ecological footprint (EF), the situation is mostly unchanged worldwide, especially in developing countries with poor equipment for efficient energy generation, with a growing threat of global warming due to unsustainable energy consumption and its disastrous environmental effects. Therefore, this study sought to analyze the ecological footprint of energy consumption in Ijebu Ode. A descriptive cross-sectional method was employed, and primary data were sourced from systemically sampled 400 households using structured questionnaires, analyzed descriptively using Microsoft Excel, and inferentially using the ecological footprint mathematical model. Findings revealed the overall EF of energy consumption in Ijebu Ode at 0.07 gha/capita, constituting about 6.7% of the city EF share, with electricity having the major share (0.04 gha; 51.9%), followed by gas with a footprint of 0.02 gha (26%). The lowest of the energy footprints were kerosine, charcoal, and firewood, with 0.003 gha (3.9%), 0.002 gha (2.6%), and 0.001 gha (1.3%), respectively. Thus, we conclude that Ijebu Ode has sustainable energy consumption, and therefore calls for practical policy directives aimed at improving our natural gas distribution potential to facilitate household availability and affordability in light of our reputation as the highest natural gas reserve holder in Africa.

Keywords: Ecological footprint; Energy consumption; Environmental Sustainability; Renewable energy; Sustainable energy

Introduction

Presently, rethinking energy consumption and environmental sustainability remains on the front burner of academic and scientific discourse, particularly with increasing energy utilization and fossil fuel-based energy systems generating huge environmental concerns. Studies have identified unsustainable consumption and the diminishing planet's ecological capital as one of many of the main causes of environmental degradation and climate change (Ahmed & Wang, 2019; Ahmed et al., 2020; Omojolaibi & Nathaniel, 2020). This is most concerning for fossil fuel utilization because of its high carbon emissions and overall impact on environmental degradation, as evident from continued global warming.

It has been documented by the Global Footprint Network (GFN) (2018) that around 80 percent of the world's populace resides in countries with substantial environmental concerns, and almost all emerging countries are experiencing ecological deficits, including Nigeria, with an ecological deficit of -0.4 gha (GFN, 2022). The ecological footprint (EF), which estimates the bio-productive surface required to support a population, was first introduced by Rees and Wackernagel in 1992 (Wakernagel & Rees, 1996). The ecological resources that a defined population needs to generate the resources it uses and absorb the waste generated, particularly carbon emissions, are regarded as the EF demand (Bello et al., 2018; Kassouri & Altntaş, 2020; Long et al., 2020). It is an accounting tool for regulating and determining the natural resources used in a community (GFN, 2018) and has roots in the sustainability principle, which asserts that our consumption of renewable assets should not exceed their potential to reproduce (Daly, 1990). Studies have proven the influence of energy consumption on EFs, notably fossil fuel sources known for their large carbon emissions, which are worsened by the fact that human growth depends on energy at the cost of sustainability. For example, fossil fuels have been shown to reduce the value of the environment by increasing the carbon and ecological footprint (Ahmed et al., 2019). In a related study, Nathaniel (2020) stated that excessive energy usage increases Indonesia's EF statistics over the long and short term. In another pertinent study, Khan and Hou (2020) discovered a positive association between energy consumption per person and EF levels. Ahmed et al. (2020) highlighted comparable findings for the Group of Seven nations. Thus, the influence of energy consumption on the EF is clear from the studies cited above.

Nevertheless, despite increasing evidence showing how unsustainable energy consumption contributes to our already rising EF, the situation remains mostly unchanged worldwide, particularly in developing countries with poor equipment for efficient energy generation. Developing countries have been found to consume more non-renewable energy than renewable energy because of insufficient investment in the sustainable energy sector (Hu et al., 2018), which is expected to account for 65 percent of global energy consumption by 2040 (Energy Information Administration (EIA), 2013). Global warming concerns will only grow because of continued, unsustainable energy use and its disastrous environmental effects.

However, little research has been conducted on household EF in Nigeria, with most concentrating on a specific region of the nation (Ojo & Abd'Razack, 2018; Fadeyibi et al., 2020). As a result, our study fills this gap by analyzing the EF of energy in Ijebu Ode, southwest of the nation, and aims to offer empirically based knowledge that will guide future policies for clean energy and environmental sustainability in Nigeria. This study is structured into five sections: introduction, literature review, materials and methods, results and discussions. Each section examines a different part of the study on ecological footprint of energy consumption in Ijebu Ode.

Literature Review

Energy Consumption and the EF Nexus

The production and use of energy have been shown to play a significant role in environmental sustainability as well as economic growth and development. Numerous studies have examined how energy use affects EF levels. For instance, Khan and Hou (2020) in a recent study reported a positive correlation between per capita energy usage and EF levels in 38 International Energy Agency (IEA) countries. In a further related study by Nathaniel (2020), it was demonstrated that the long- and short-term EF of Indonesia increased as a result of high energy consumption. Similar conclusions have been documented in the Group of Seven (G7) nations (Ahmed et al., 2020) and France (Ang, 2007).

In an attempt to promote sustainability in economic development, several nations have turned their attention to clean and renewable energy sources because of the impact of nonrenewable energy on carbon emissions (Zaidi et al., 2018). Hence, numerous studies have examined the relationship between the consumption of renewable energy and EF, in line with the concept that adding more renewable energy sources to a country's energy grid will ensure environmental sustainability. The use of renewable energy has been demonstrated to reduce the EF of several Organization for Economic Cooperation and Development (OECD) nations (Destek & Sinha, 2020). Similar findings were found in emerging nations from Asia (Sharma et al., 2020) and 16 European Union countries (Alola et al., 2019). Similarly, Naqvi et al. (2020) showed statistical support for increased renewable energy use to lower EF in the context of high- and upper-middle-income nations. However, no statistically significant effects of renewable energy use on EF were found in lower-middle- and low-income countries.. In contrast, notable studies have highlighted dissimilar results regarding the impact of energy consumption on EF. According to Nathaniel and Khan (2020), the utilization of renewable energy has little impact on the EFs of a few Association of Southeast Asian Nations (ASEAN) member countries. Moreover, the cause of the increasing levels of EFs was found to be higher non-renewable energy usage. Equally notable findings revealed that the use of renewable energy is harmful to the sustainability of the environment in a recent study of 15 economies with the largest carbon emissions (Usman et al., 2020). The authors further claimed that the increased use of renewable and non-renewable energy increased EFs. However, the marginal effects of renewable energy consumption on EFs were shown to be relatively less significant when compared to non-renewable energy; thus, achieving environmental sustainability through renewable energy is a relatively better strategy (Usman et al., 2020).

In addition, although it has been demonstrated that high utilization of non-renewable energy leads to high levels of EF, data for individual countries showed that renewable energy had little impact on EF. For instance, a link between nonrenewable energy usage and positive outcomes was found in Thailand, Vietnam, and Malaysia (Nathaniel et al., 2020), while higher consumption of renewable energy was associated with lower EF levels, but only in the cases of Israel and Jordan (Nathaniel et al., 2020). Thus, the authors concluded that the use of renewable energy did not have an impact on the EFs of Middle East and North African (MENA) countries. In contrast, it was discovered that nonrenewable energy increased the EFs of MENA nations as a whole, as well as for Algeria, Yemen, Iran, Tunisia, Oman, and the United Arab Emirates (Nathaniel et al., 2020). Thus, the use of renewable energy does not ensure a decrease in the EF, as suggested by the ambiguous results reported in the aforementioned studies. Hence, there is a need to examine the links between many countries.

Overall, there is no denying that renewable energy consumption has hitherto increased environmental pollution (Bulut, 2017). Nevertheless, compared to non-renewable energy, the overall effect of renewable energy on climate change is less significant and less expensive (Sinha et al., 2018; Chen et al., 2019). In this sense, empirical evidence from China shows that coal (a nonrenewable energy source) significantly increases the level of pollution in the country. Similarly, research has suggested that renewable energy use is more environmentally friendly in the long term (Dogan &

Seker, 2016; Bhattacharya et al., 2017; Inglesi-Lotz & Dogan, 2018).

Energy situation in Nigeria

As an energy giant, Nigeria is Africa's most productive oil-producing nation, which, together with Libya, accounts for about two-thirds of the continent's crude reserves (Oyedepo, 2012) and ranks second only to Algeria in natural gas production (Sambo, 2015). Among the various energy consumption sectors, the household sector accounts for the major share of energy consumption, accounting for approximately 60% of the overall share (Energy Commission of Nigeria, 2003). According to Dayo et al. (2004), the household domain has consistently accounted for over half of the country's domestic energy consumption, varying between 55 percent and 61 percent. Among the main energy-consuming activities in households are cooking (91%) and lighting (6%), and the remaining 3% can be linked to the utilization of electrical appliances (Energy Commission of Nigeria, 2005).

Several studies have also highlighted the major energy sources among Nigerian households, which include both renewable and non-renewable sources. Nigeria, although blessed with abundant renewable energy sources, is limited by its technological capacity to utilize the full potential of these sources. In support of this, Abiodun (2003) reported that the majority of Nigerian households rely on kerosine for cooking, while relatively few use gas or electricity. Similarly, a detailed distribution of Nigeria's household cooking energy indicates electricity (0.45%), liquefied natural gas (LPG) (0.74%), natural gas (1.26%), biogas (0.23%), kerosene (19.8%), charcoal (3.13%), and firewood (72.18%) (Buba et al., 2017). Further evidence suggests that Nigeria's household energy consumption comprises of electricity (4%), kerosene (13%), gas (1%), and firewood. (82%; Etege & Alabi, 2011). These have continued to pose a serious threat to environmental sustainability and therefore call for an energy-transformative approach to ensure an evidence-based shift to cleaner and more sustainable energy consumption..

Materials And Methods

Study Area

The study was conducted at Ijebu Ode, which is about 60 km northwest of Lagos and the second-largest city in Ogun State, southwest Nigeria, with a land mass of 192 km2 and 154,032 population (National Bureau of Statistics (NBS), 2007) (see figure 1). The city of Ijebu Ode is known for its fast-growing and widely distributed suburban zone, with an estimated current population of 367,749 and a population growth rate of 3.36 percent, according to the World Population Review (2022).

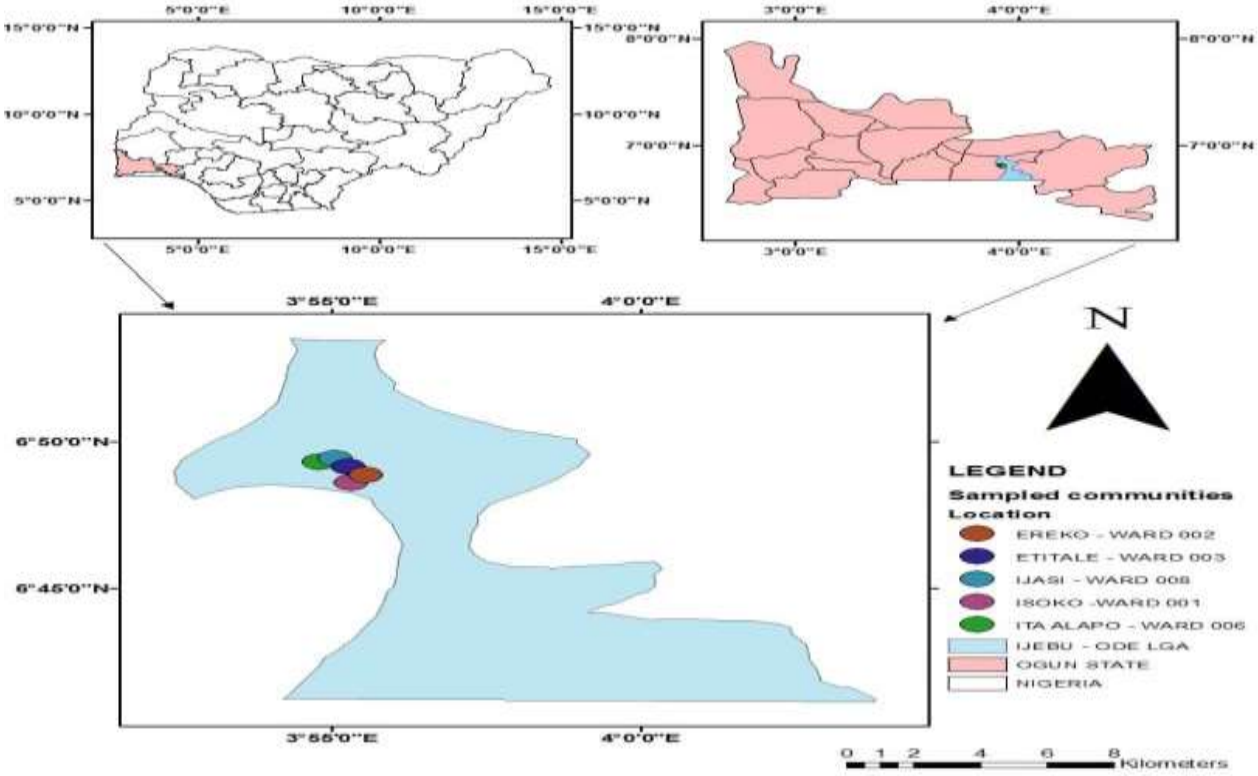

Figure 1: Ijebu Ode spatial map of the sampling locations (Otto et al., 2022)

Sample and Sampling Techniques

To create the required 400 samples, five (5) wards were selected at random from a total of eleven (11) wards of the city, and eighty (80) participants were selected from each ward to create the samples. Residential homes were chosen at intervals of every fifth home in each of the chosen wards using a systematic random sampling technique. An aggregate sample of 400 participants was estimated using Slovin's sample size determination method (Eq. 1), with an error margin of 0.05, and a 95% confidence level.

$$n = \frac{N}{1 + Ne^2} \qquad \text{Eq. 1}$$

(Ellen, 2020).

Where;

n = sample size
N = population size
e = margin of error

Data Collection Procedure

The primary data for this study were provided by a structured questionnaire distributed to a systematically selected sample of 400 households. The primary dataset consisted of 400 household questionnaires used to collect information about energy consumption and expenditure from respondents in the five Ijebu Ode wards of Itantebo/Ita, Porogun I, Odo/Esa, Ogbin, Ijasi/Idepo, and Isoku/Ososa. Additional sources of secondary data included the Global Footprint Network, Food and Agriculture Organization, National Bureau of Statistics (NBS), Nigerian Electricity Regulatory Commission (NERC), and other web-based publications (Table 1). To ensure the presentation of a geographical analysis of EF in Ijebu Ode, the sampling locations were recorded using a global positioning system (GIS) to build a GIS database.

Table 1: EF Data Needs and Sources

S/n	Data	Source
1	Socio-demographic Data	Author’s Survey
2	Ijebu Ode’s Population	NBS (2007)
3	Energy Consumption	Author’s Survey
4	Tariff/Kwh of Electricity	NERC (2015)
5	Yield Factor	GFN (2019)
6	Equivalence Factor	GFN (2019)

Data Analysis Approach

Inferential statistics were employed to analyze the data collected for this study using mathematical models to calculate the ecological footprint (see Eq. 2), and the results were visualized using pictorial variables such as histograms and pie charts. Descriptive analysis was performed using distribution tables with simple percentages in Microsoft Excel.

Determination of EF of Energy

According to Shakil & Muhammed (2018), as cited by Fadeyibi et al. (2020), the greenhouse gas (GHG) conversion standard (2010) was adopted to evaluate the EF of energy consumption using six categories of energy sources, including electricity, generators, gas, kerosene, charcoal, and firewood. The amount of energy gathered during the field survey was measured in kWh. Because 1 kWh is valued at the N27.40 Nigerian Naira (Nigerian Electricity Regulatory Commission (NERC), 2015), the overall amount of energy from each source was converted to an energy value in kWh by dividing the amount by the N27.40 naira, while the energy value for electricity was determined in MJ by dividing the energy value in kWh by 0.2778 kWh. Additionally, the updated GHG emissions of various fuels for 2019 were used to calculate the embodied energy in MJ per kg and CO_2 emissions in kg/MJ. Subsequently, the footprint was calculated and expressed in “global hectares” (gha) by dividing the energy value in MJ by the national yield factor for forest land (0.26) (GFN, 2019), and multiplying the result by the equivalency factor (1.29) (GFN, 2019), CO2 emissions (kg/MJ), and the resulting value divided by the total population value of Ijebu Ode (NBS, 2007), to give the EF of energy consumption in gha/capita (see Eq. 2).

$$\boldsymbol{EF_e = \sum_1^6 \frac{EV}{Y_f} \times E_f \times CO_2\, gas\, emmission\ \frac{kg}{MJ}} \quad \text{Eq. (2)}$$

(Fadeyibi *et al*., 2020):

Where;
EFe = EF for energy by energy usage mode (gha/capita),
EV = Energy Value (MJ/kg)
CO_2 *Emission* = carbon dioxide emission (kg/MJ) and
Y_f and E_f = yield and equivalence factor

Results

The various energy types utilized by the household surveys were categorized into the following categories: electricity, gas, kerosene, charcoal, firewood, and generator (Figure 2). The footprint analysis of the different energy categories reveals that electricity has an EF of 0.04 gha (51.9%), and the largest of the EF shares was followed by gas with 0.02 gha (26%), and generators with 0.011 gha (14.3%) (Figure 3). Also, the EF of kerosine consumption is 0.003 gha (3.9%), charcoal is 0.002 gha (2.6%), and firewood is 0.001 gha (1.3%), according to the analysis (figure 3). However, the overall EF of energy consumption was shown as 0.07 gha per capita.

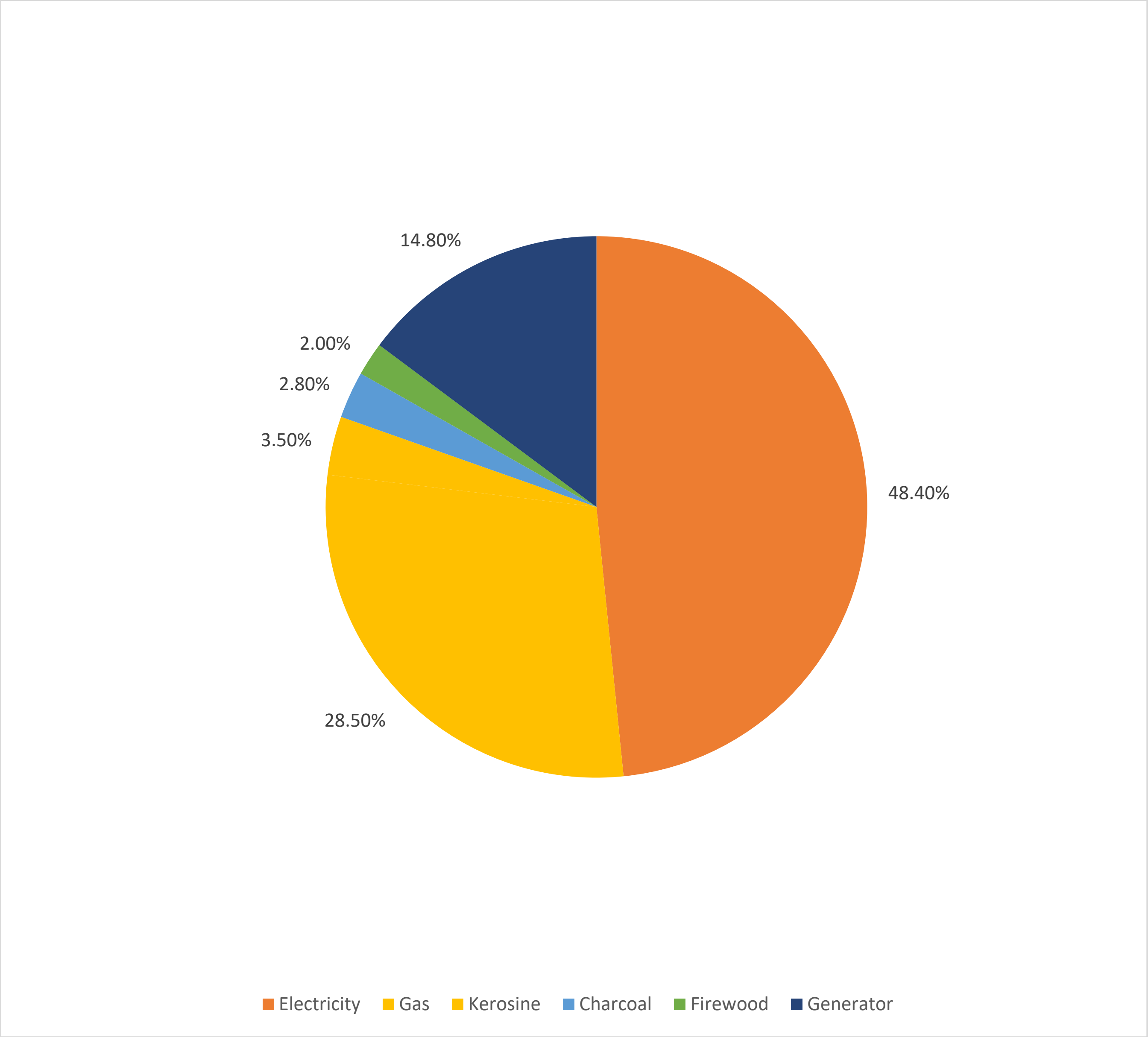

Figure 2. Percentage distribution of annual energy consumption by categories

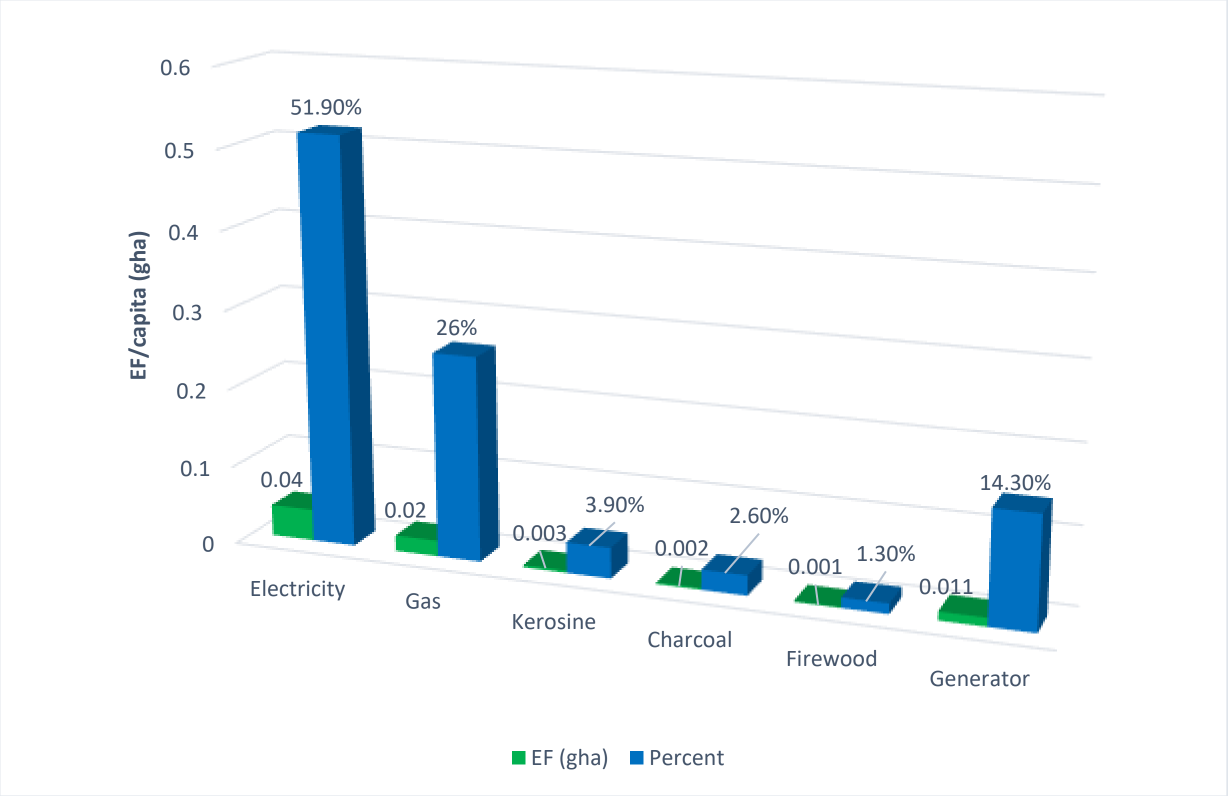

Figure 3. EFs of various energy categories and their percentage distribution

Discussions

The present study was initiated to evaluate the EF of energy consumption in Ijebu Ode. The findings suggested that the EF of energy in Ijebu Ode was shown to be 0.07 gha per capita, contributing to approximately 6.7% of the total EF share of Ijebu Ode (figure 3). This finding suggests that Ijebu Ode's energy usage is sustainable, as any footprint calculation of more than 1.0 gha per capita denotes unsustainable resource use, according to Razack and Ludin (2014). Moreover, the result may have been caused by modern and sustainable energy (electricity and gas) utilization by the residents, as opposed to biomass and traditional energy sources (kerosine and firewood), which have been scarcely utilized (figure 2). A study suggested that modern energy for Nigerian household cooking has shifted to electricity and "liquefied petroleum gas" (LPG) (Nnaji et al., 2021). Moreover, researchers have found that the continuous use of clean energy significantly reduces the EF (Sharif et al., 2020; Sharma et al., 2021; Xue et al., 2021). Similarly, studies have shown that using traditional energy sources such as fossil fuels and wood as energy sources significantly increases CO_2 emissions (Shahbaz et al., 2013; Anser, 2019; Chen et al., 2019), and the ecological footprint has been found to be significantly related to CO_2 emissions (Abbas et al., 2021). Therefore, the current results corroborate those of Ojo and Abd (2018) and Khan and Uddin (2018). However, this is in contrast with Fadeyibi et al. (2020) and Begum and Pereira (2012), who in their respective studies reported that energy is the largest contributor to the EF share in Ilorin (44%) and Malaysia (53%), respectively. A possible explanation for this disparity may be the variation in the utilization and affordability of the major energy sources. In the former case, the high energy utilization was attributed to the high usage of generators that use fossil fuels (gasoline and diesel), which are known for their high CO_2 emissions, while the latter is linked to the subsidization of energy, which increases consumption owing to its affordability. It has been noted that having access to energy sources that are more efficient indicates greater levels of energy consumption (Pachauri and Spreng, 2004). Consequently, studies have found that extensive use of energy increases carbon dioxide emissions and the ecological footprint (Tiba & Omri, 2017), while fossil fuels are known to increase CO_2 emissions (Anser, 2019) and the ecological footprint (Szigeti et al., 2017).

Further analysis revealed that electricity consumption has an EF of 0.04 gha (51.9%), which constitutes the major share of the energy footprint, compared to the footprint of generator usage with 0.011 gha (14.3%), which is the third largest share of the energy footprint (figure 3).However, they are unconnected with a relatively steady supply of electricity in the area. For example, Ogun State has been reported to be one of the first four states in Nigeria, with the highest electricity supply as a result of its huge industrial activity (Power, 2019). In addition, the result may be explained by the record of huge estimated bills (that do not depend on the actual energy consumed) paid by unmitigated or non-prepaid residents who do not have access to a smart prepaid electricity meter. An empirical study found that non-prepaid or unmetered customers are often highly overbilled (Ohajianya, 2021), and about 80% of consumer complaints received by the NERC are about estimated and excessive bills (Arimoro et al., 2019). Similarly, the continuous skyrocketing of fuel prices over the years has made it practically and economically difficult for households to sustain the use of generators as an alternative source of power, except for commercial and energy-dependent outfits, and a few well-to-do families. However, our result is a confirmation of the findings of Ojo & Abd'Razack (2018), who established that electricity has the highest energy footprint in Bida with 0.06 gha (64%) of the entire energy share. In addition, a study assessing household energy consumption in major Nigerian cities (Warri, Port Harcourt, and Calabar) by Okuma et al. (2021) revealed that electricity has the highest consumption, with 67.7% of all energy sources, second only to kerosene.

By contrast, Fadeyibi et al. (2020) demonstrated that electricity has the lowest footprint of the total energy footprint share in Ilorin, which, according to the authors, is due to the low supply of electricity. Nonetheless, the disparity may also be due to the fact that unlike Ijebu Ode, Ilorin, as a metropolitan city, has many of its electricity consumers using prepaid meters, which overrules the chances of excessive bills that come with estimated billings. Our findings show that, despite intermittent power supply, most residents continue to rely heavily on electricity owing to the high economic cost of using generators, which can only be sustained by a relatively small number of economically stable individuals and commercial or business outfits. Several studies have reported that electricity usage has a low impact on EF because of its low-carbon emissions (Borisade et al., 2020; Sharif et al., 2020). These results have policy implications and call for realistic policy decisions on the need to revamp the national grid to ensure a steady supply of electricity for sustainable energy consumption, as well as reduced EF.

In addition, the results further revealed that the EF of gas consumption is 0.02 gha (26%), which is second only to electricity in the energy consumption footprint (figure 3). The withdrawal of a government subsidy on the price of kerosene by the Nigerian government in 2016 may not be unrelated to the rise in the consumption of this contemporary cooking fuel, which, according to the National Population Commission (2019), witnessed an increase in LPG to 15% as the preferred cooking fuel in homes. Accordingly, Eleri (2021) opined that household cooking accounts for a large percentage of Nigeria's energy consumption, translating into a significant latent demand for LPG. Similarly, the NBS report of 2020 indicated that clean-cooking access has moved from a very low level of less than 5% to about 10% due to new efforts to promote LPG (NBS, 2020), which is a sustainable cooking fuel because of its lower carbon emissions compared to other fuel types (Borisade et al., 2020). Other studies have also reported a high utilization of LPG as a household energy source (Okuma et al., 2015; Okuma et al., 2021).

The present finding is in agreement with a similar report by Ojo and Abd'Razack (2018), who demonstrated the EF of gas consumption to be 0.01 gha (9%) of the energy footprint of Bida, but disagrees with Fadeyibi et al. (2020). This disagreement may be a result of the regional imbalance in the consumption of LPG, with 65% estimated modern fuel use for cooking in most of Nigeria’s southern states (Nnaji et al., 2021). By implication, it is advisable to note that cooking activities account for the high energy consumption in households (Borisade et al., 2020). Hence, LPG utilization, especially among households, should be encouraged through resource availability and affordability owing to its low carbon emissions, which have been documented (Xue et al., 2021), to reduce ecological footprints. Similarly, households can embrace and use biogas produced from domestic garbage, which is a sustainable but less expensive source of clean energy. According to empirical studies on the importance of biogas, animal and agricultural wastes are used to produce a large amount of biogas (Abubakar et al., 2022), notably in nations such as India, Greece, China, and Ukraine (Talevi et al., 2022; Aravani et al., 2022; Kucher et al., 2022). A recent study by Ahmed et al. (2022) indicated that placentas have the same biogas potential as other organic wastes in renewable energy production.

Additionally, the EF of kerosine consumption was shown to be 0.003 gha (3.9%), charcoal 0.002 gha (2.6%), and firewood 0.001 gha (1.3%), which were the lowest footprint shares, according to the analysis (figure 3). These results are consistent with the studies of Ojo and Abd'Razack (2018) and Fadeyibi et al. (2020). Nonetheless, the results may be unrelated to the rising cost of kerosine, which was the main source of energy in most households, but following subsidy withdrawal for kerosene in 2016, there was a dip in the use of over 40% between 2013 and 2018, as evidenced by the use statistics dropping from 26% to 15% (Nnaji et al., 2021). Similarly, while there is widespread usage of fuelwood for cooking across the country, there is a significant regional disparity. For instance, very few households that primarily cook with wood have been documented in the states of Ogun and Lagos, which is not unconnected to the fact that the distribution systems of LPG are more robust and household incomes are higher in the wealthier southern states (Eleri, 2021). Moreover, Maina et al. (2020) reported that a dwindling pattern had been documented in the past years, with fuelwood fetch declining, while the other fuel sources increased, with a significant increase in LPG usage. This is in further support of our finding earlier reported (figure 3). However, it is instructive to note that, aside from its significant impact on carbon emissions and EF upsurge (Chen et al., 2019; Abbas et al., 2021), it has been estimated that around 45,000 hectares of forest are lost annually to illegal felling of trees and shrubs for domestic biomass and charcoal production (Adegoke & Lawal, 1999), and if the trend continues, the implication is that the forest resources will have been greatly depleted (Sambo, 2006).

By implication, this study proves essential in establishing the literature on the EF of energy consumption in Ijebu Ode, with crucial policy implications on the need to adjust the nation's energy portfolio and institute a paradigm shift toward clean and sustainable energy sources. However, the authors were not ignorant of some of the observable limitations of the study, which involved delimiting it to the household level. Therefore, evaluation of the EF of energy consumption at the city or regional level in the country is recommended.

Conclusion

This study aims to evaluate the EF of energy consumption in Ijebu Ode for environmental sustainability. Findings revealed that the energy consumption in Ijebu Ode has a per capita EF of 0.07 gha, which represents 6.7% of the total EF of Ijebu Ode. The main contributor to the energy footprint was electricity (0.04 gha; 51.9%), followed by gas (0.02 gha; 26%). The smallest contributors to the energy footprint were kerosine, charcoal, and firewood (0.003 gha; 3.9%, 0.002 gha; 2.6%, and 0.001 gha; 1.3%, respectively). We infer that Ijebu Ode has a sustainable pattern of energy consumption that supports its environmental sustainability. We suggest policy actions to increase the availability and affordability of renewable and clean energy sources to improve and ensure sustainable energy consumption.

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Competing Interest

There are no opposing issues disclosed by the authors.

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RESEARCH ARTICLE

To Study the Contribution of Price Factor Towards the Purchase Intention of EV Market in Malaysia Among Generation Y Consumers

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Abstract

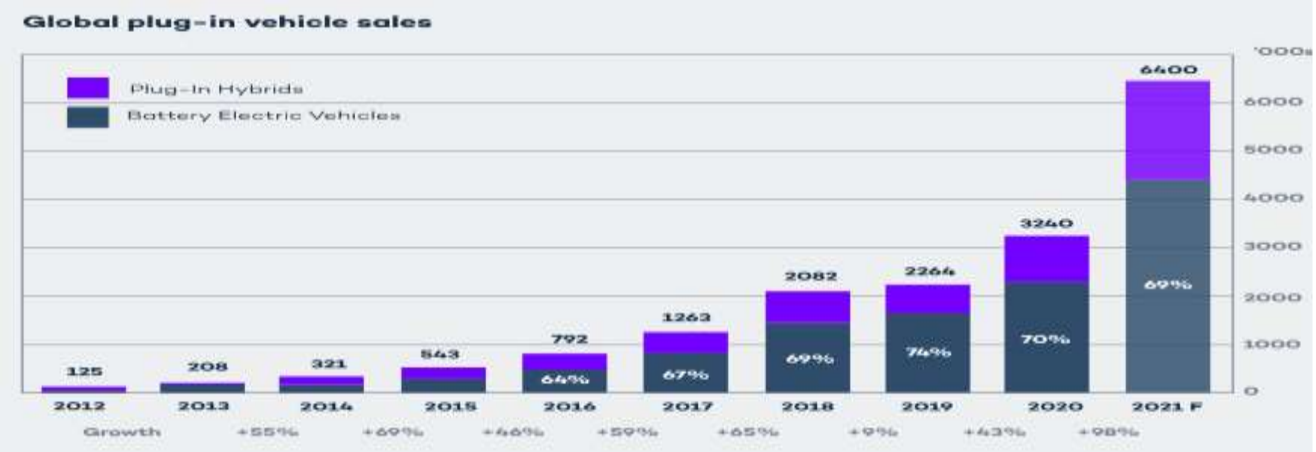
The increasing demand towards the electric vehicle (EV) had prioritize the importance of the study towards the understanding on the purchase intention of the consumer market for the EV in Malaysia among the generation Y consumers. The previous study had suggested that the major contribution shift towards the EV market had been motivated by the environmental conscious for the individuals leading to higher purchase intention among the individuals. The suggestion on the previous study had suggested the evidence pointing to the significant positive relationship between the environmental conscious against the purchase intention of the consumers. The methodology of the research design had observed the quantitative method to put into picture to conduct the quantitative analysis based on the data input from the collection of sample size of 150 respondents from the distribution of the questionnaire from the target population of the Generation Y consumers. The findings had pointed out the evidence suggesting the presence of the significant positive correlation and regression relationship between the two variables indicting the similar findings as the previous research study. This had led to the achievement of the objective of the research drawing the significance of the study to conclude the outcome of the research.

Keywords: Electric vehicle; Generation Y; Malaysia; environmental conscious; purchase intention

Introduction

The electric car market is still in its early stages, while gasoline-powered and hybrid vehicles dominate the automotive sector. Despite the efforts of companies like Tesla, it will take time for the market demand for EVs to grow as consumers build trust in the technology and begin to convert their preferences to EVs (Carlucci, Cira & Lanza, 2018). Figure 1 shows that there is a rising global demand for EVs, indicating a large untapped market potential that should eventually translate into a rising sales trend. EVs only held 9.1% of the global market in 2021, according to data from that year, so there is clearly room for expansion (Zhou & Li, 2018). But there is still a paucity of understanding of the factors that motivate people to buy EVs (Doleschal, Rottengruber & Verhey, 2021).

Figure 1: Global Plug-in Vehicles Sales



In response to concerns about climate change and the depletion of natural resources, electric vehicles (EVs) were introduced to the market (Austmann, 2021). The performance of EVs is also projected to deliver higher sustainability as well as a quieter and more pleasant driving experience compared to conventional gasoline motor cars, therefore they are recognized to bring better experience to the users (Dumortier et al., 2015). In light of the need to address environmental concerns, electric vehicles (EVs) are widely seen as the sector's future standard of transportation (Fan, Huang & Wang, 2021). Accordingly, the industry must quickly implement the transformation by recognizing the change in legislation and market trend and encouraging the EV market to customers.

As Generation Y gradually enters the consumer market, they will be the primary target audience for electric vehicles. As a result, the proportion of millennials among car buyers is expected to rise. Consumer market "adults" are the persons currently in their 30s and 40s who were born between 1981 and 1994. (Guo et al., 2020). However, the generation Y consumer's thinking and expectations will become the central research subject as different generations are exposed to the generation gap and its possible effects on consumer preferences (Austmann, 2021). The millennial generation, for instance, places a higher value on the car's unique features and design than on its basic technical specifications (Zhou & Li, 2018). In general, members of Generation Y are portrayed as a spending-happy generation with lofty lifestyle expectations. This generation will widen the wealth gap between its predecessors and itself (Golob & Kronegger, 2019). As a result, this research was prompted to delve deeper into the potentially significant factors that will affect consumer behavior in purchasing the EVs market in the automotive industry market, as this would pressure the automotive industry to adopt the market shift in the consumer behavior for the rising of generation Y.

It was obvious why we were concentrating on the millennials; they represent the demographic that will be driving cars into the foreseeable future. In addition, the preferences of future consumers will be impacted by the interconnectedness between generation Y and the dwindling natural resources and the changing environment (Golob & Kronegger, 2019). As a result, members of Generation Y are more concerned about the effects of climate change on future generations, and this has prompted a shift toward greener products like electric vehicles (Zhou & Li, 2018). Further, the EV product's innovation had been enhancing its design and creativity, which grabbed the attention of the younger generation (Guo et al., 2020). Consequently, the primary focus of this research will be on gaining an understanding of the target demographic of generation Y by delving into the reaction and preference that leads to the motivation of the buy intention. Thus, it is important to investigate why millennials are interested in buying electric vehicles.

EVs were introduced to the market to minimize carbon emissions from motor cars as well as usage of fossil fuels, which are blamed for natural resource depletion (Austmann, 2021). Furthermore, EVs are recognized to provide a superior experience to consumers because their performance is projected to provide greater sustainability as well as a quieter and more comfortable driving experience when compared to regular gasoline motor cars (Dumortier et al., 2015). With the resolve of environmental concerns, EV are predicted to become the future of motor vehicles in the automotive sector, as a change in energy source is believed unavoidable (Fan, Huang & Wang, 2021). To achieve this goal, it is critical for the industry to adapt the shift as soon as possible, with the promotion of the EV market towards consumers and accepting the shift in policy and market trend.

Literature Review

Studying consumer behavior from the viewpoints of attitude, subjective norm, and perceived behavioural control is central to the theory of planned behavior (TPB). Within the TPB model, these three convictions are identified as the key drivers that establish the individual's intent when it comes to preference and decision making. In this study, the TPB will be used to learn how millennials' attitudes, subjective norms, and perceived behavioral control all play a role in their decision to buy an electric vehicle (Bosnjak, Ajzen & Schmidt, 2020). When it comes to a person's frame of mind, the observable response they exhibit in a given setting in relation to a certain aim is what the behavioural observer will focus on (Hsu & Huang, 2010). Subjective norms characterize the attention paid to the application of normative beliefs, when those beliefs are shaped by the individual's own perceptions of the normal norm and of his or her peers (Ajzen, 2020). It is important to consider the individual's sense of control while trying to explain why they may be unable to accomplish a given behavior.

The factor of price determines whether or not a certain product or service is within a customer's financial reach, it ultimately becomes the deciding element in how the customer chooses to use the product or service. As electric vehicles (EVs) are currently sold at premium pricing, cost has become a more important consideration in the buying process (Hagman et al., 2016). According to Dumortier et al. (2015), the higher initial purchase price of electric vehicles compared to conventional gasoline vehicles is a major contributor to the higher total cost of ownership, which in turn may have an effect on consumer behavior. It is expected that as electric vehicles (EVs) continue to improve and new manufacturers, like Tesla, introduce cutting-edge EVs to the market, EV sales will rise.

Nonetheless, the EV's high operating costs will raise new problems within the pricing category. (Lin, 2014). Customers may be put off by the product's expensive entry price and ongoing maintenance fees, prompting them to go elsewhere.

Because depleting natural resources like gas and oil of petroleum has become one of the most significant climate concerns on the market, Hagman et al. (2016) had emphasized the need for a shift in the alternative market, where the EV market had been rising in importance and popularity among the consumer market. However, the price of EVs continued to be high, which was an additional barrier to the growth of the EV market; this was because the high production costs of EVs were being passed on to consumers in the form of higher prices, which in turn became a major motivating factor in whether or not people planned to buy EVs. As Bashash et al. (2011) pointed out, the introduction of the EV market has made electric vehicles the future of the automotive industry, and the EV model has been shown to be beneficial in decreasing energy and resource use. While the initial purchase price of an electric vehicle may be higher than that of a conventional vehicle, the long battery life and low operating costs of EVs are likely to be viewed as a positive selling point by buyers. Nonetheless, Hagman et al. (2016) had made it obvious that despite the positive effects stemming from the use of EV, skepticism was sparked where the pricing for the EV would continue as premium above the gasoline car, which would become an issue on the affordability for the consumer. The increased cost may now play a role in discouraging EV purchasing intent. According to Hagman et al. (2016), the rising cost of EVs will become a major deterrent for consumers considering making a purchase in the sector. On the other hand, it is theorized that the younger generation of consumers may have a different perspective, with the tendency for younger consumers to have a favorable buy intention for EVs notwithstanding the price.

H0: There is no significant of positive impact of price towards the purchase intention within the EVs market for generation Y

H1: There is significant of positive impact of price towards the purchase intention within the EVs market for generation Y

Methodology

Quantitative methods were used to collect and analyze the research's data. By establishing empirical proof through exact measurement and numerical information, the results of the study's data analysis can be taken more at face value, thanks to the advantages offered by the quantitative analysis (Zikmund et al, 2013). Not only that, but quantitative techniques permit the examination of very large samples (Apuke, 2017). The use of deduction will be central to this quantitative investigation. The goal of using deductive reasoning in research is to arrive at a conclusion after first formulating a hypothesis that will be evaluated using a set of observations (Zikmund et al, 2013).

Both main and secondary information may be uncovered throughout the course of data collection. There are good and bad aspects to both types of information. It is recommended that primary data collection, in which information is gathered from the original source itself, be prioritized in the context of this study (Sekaran & Bougie, 2016). Questions will be sent out to Malaysia's millennials to gather information for this study.

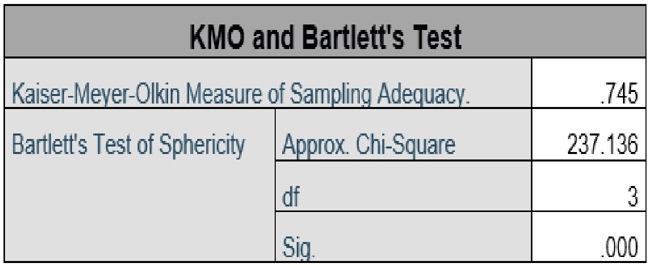
Convenience sampling, a form of non-probability sampling, will be employed to select participants from the study community. According to the definition of "convenience sampling," a researcher chooses a subset of the study population whenever it is most convenient for them to do so. Using convenience sampling can help a researcher save time and money while still gathering useful data for their study (Sharela, 2016). According to the sample size reference, the study will collect 150 samples from the target demographic (the typical range for a research study's sample size is between 150 and 200 samples).

The quantitative study approach will be used in this study's application of the research methodology; SPSS will be used to generate the research's output, and its statistical results will include a factor analysis to confirm the accuracy of the questionnaire's responses, as well as a reliability analysis to check for inconsistencies and establish confidence in the results (Sharela, 2016). The study's outcome and goals will be drawn from the results of a combination of a correlation analysis and a regression analysis designed to shed light on the strength of any beneficial association between environmental consciousness and customers' propensity to make purchases (Sekaran & Bougie, 2016).

Discussion and Findings

The quantitative analysis will be proceeded to observe the significant in the data analysis in the statistical output as performed by the output from the SPSS software.

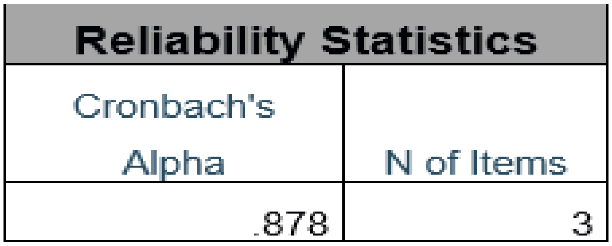
Table 1: Factor Analysis for Price



KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.745
Bartlett's Test of Sphericity	Approx. Chi-Square	237.136
	df	3
	Sig.	.000

Table 1 displayed the factor analysis result for the data set received from the questionnaire distribution on the variable of environmental consciousness. The factor analysis produced a KMO value of 0.734, which above the benchmark KMO value of 0.5 as specified in the study's research methodology, indicating that the data set is substantial enough to be used for further quantitative analysis.

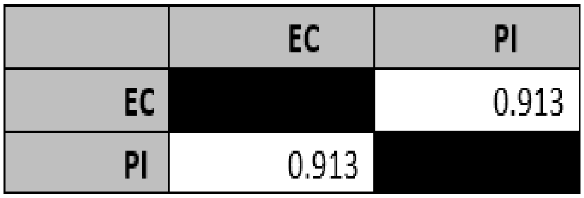
Table 2: Reliability Analysis for Price



Reliability Statistics	
Cronbach's Alpha	N of Items
.878	3

Table 2 displays the reliability analysis result for the variable of environmental consciousness based on the data set collected from the questionnaire. Cronbach's Alpha was 87.8%, which exceeded the standard of 70% provided in the study's research methodology, indicating that the data set is credible.

Table 3: Correlation Analysis



	EC	PI
EC	■	0.913
PI	0.913	■

EC => Environmental Conscious

PI => Purchase Intention

Table 3 had demonstrated the output for the correlation analysis testing the variable between the environmental conscious against the purchase intention for the consumers. The Pearson Coefficient Correlation had recorded 0.913 with the p-value of 0.000 had been showing strong evidence to suggest the presence of the positive correlation between the two variables. The strength of the positive correlation had been strong where the increase or decrease of the degree for the environment conscious will be followed by the almost the similar impact on the purchase intention of the consumer towards the EV market.

Table 4: Summary of Linear Regression Model

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.198	.128		1.543	.125
	EC	.656	.125	.649	5.232	.000
a. Dependent Variable: PI						

EC => Environmental Conscious

PI => Purchase Intention

The Table 4 demonstrate the final output of the linear regression model as derived from the independent variable of environmental conscious against the dependent variable on the purchase intention of the consumers in the EV market. Based on the summary for the regression analysis reference to Table 4, the p-value recorded for the variable of environmental conscious had shown 0.000 which provide the indication that the influence from environmental conscious is significant towards the change in purchase intention among the Generation Y consumers as the p-value fall below the tolerance level of 5%.

With reference to the result output in Table 4, the presence of the significant in the positive relationship between the environmental conscious against the purchase intention of the consumers in the EV market has posed the suggestion to reject the null hypothesis at H0 and accept the alternate hypothesis at H1 as proposed in the previous literature review for the study.

H0: There is no significant of positive impact of price towards the purchase intention within the EVs market for generation Y

H1: There is significant of positive impact of price towards the purchase intention within the EVs market for generation Y

Lin and Chang (2020) stated that consumers' environmental consciousness will motivate them to acquire products that deliver better green advantages to the environment. According to Mishal et al. (2017), environmental consciousness will provide incentive to help the environment in any way as long as the goal does not negatively impact the ecosystem. According to the empirical evidence, the study's findings indicate that being environmentally conscious will have a substantial positive impact on Gen Y customers. This could imply that climate change has become a more worrisome element, and that with EV becoming the image for the green environment, more Gen Y are supporting the purchase of EV in order to save the environment for the future. Lin and Chang (2020) stated that environmental consciousness had been addressed in conjunction with climate change, where the rising concern on environmental topics had become the spotlight for the consumer market, and where the sense of responsibility to contribute to the environment had become the factor that would influence and steer the consumer's preference towards the green environment product for the market. Mishal et al. (2017) are referencing a prior study in which there is a strong suggestion that the rising number of EV purchases are being contributed by the rising trend towards greener motor vehicles on the roads. This demonstrated that environmental consciousness remained a strong driver for the intention to acquire EV models in the Malaysian market, particularly given the Malaysian government's emphasis on encouraging the market to support the green environment.

Conclusion

To begin, the research contributed to the academic study by identifying new knowledge from the study's findings, which triggered an understanding of the potential important in the elements influencing the shift in buy intention on the consumer behavior toward the EV among Gen Y. This will be a significant contribution to narrowing the gap in the literature review where the empirical evidence may be cut down to improve the contribution to the breadth of research area.

Furthermore, the study's findings will make a significant contribution to the automobile industry, particularly at a time when the sector is actively attempting to gradually phase out gasoline motor cars for the consumer market. Based on the findings of this study, the strategic team will need to develop an effective marketing strategy based on the significant driving factors of Gen Y consumers, where the study found that quality and environmental consciousness remained as the top priorities for Gen Y consumers when it came to purchasing an EV.

Furthermore, the study on the EV market will be crucial for the automobile industry since it will allow the sector to grasp the potential significance of the acceptability level for the consumer market when it comes to launching new products into the market. The development of the EV model had resulted in a significant shift in industry expectations. In terms of the future trend in the car business, the hydrogen vehicle has risen to the forefront, with the industry hopeful about the development of futuristics motor vehicles that will eliminate the usage of batteries and be more environmentally friendly for the environment. As a result, this study will become an important reference that will be able to provide higher refence for the preparation of the future market shift and change with the introduction of future items into the sector.

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RESEARCH ARTICLE

The impact of Artificial Intelligence and Machine learning on workforce skills and economic mobility in developing countries: A case study of Ghana and Nigeria

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Abstract

This study investigates the impact of Artificial Intelligence (AI) and Machine Learning (ML) technologies on workforce skills and economic mobility in Ghana and Nigeria. Using a qualitative research design, the study involves a literature review and data collection through interviews and focus groups with workers, educators, employers, and policymakers in both countries. The study shows that the adoption of AI and ML technologies is creating a growing demand for workers with complementary skills, leading to a skills gap in the workforce as the education systems in these countries struggle to keep up with the demand. The research study highlights the need for policies and strategies to address the skills gap and promote economic mobility. The study's recommendations can inform policymakers, educators, and employers in these countries on necessary steps to prepare the workforce for the changing demands of the future of work. Overall, this study provides a comprehensive analysis of the qualitative aspects of data collection and analysis and the impact of AI and ML on workforce skills and economic mobility in Ghana and Nigeria.

Keywords: Artificial Intelligence; Machine Learning; Workforce Skills; Economic Mobility

Introduction

The adoption of artificial intelligence (AI) and machine learning technologies is transforming the workplace, and the skills required in the workforce are changing. The impact of AI and machine learning on the future of workforce skills and economic mobility in developing countries such as Ghana and Nigeria is of particular interest. The African continent is projected to have the world's largest workforce by 2035, with Ghana and Nigeria playing significant roles in this growth (Mckinsey Global Institute, 2018). As such, understanding the impact of AI and machine learning on the future of workforce skills and economic mobility is vital to the development and growth of these countries.

Recent literature highlights the need to explore the impact of AI and machine learning on the future of workforce skills and economic mobility in developing countries (Kaur & Singh, 2022; Obembe et al., 2021). While several studies have investigated the impact of these technologies on developed countries such as the United States and Europe (Brynjolfsson & McAfee, 2014; Lee et al., 2019), there is a need to understand the unique challenges and opportunities facing developing countries.

Several recent studies have highlighted the importance of addressing the skills gap created by the adoption of AI and machine learning technologies (Ali et al., 2020; Tetteh et al., 2019). The study will seek to identify the skills that are complementary to AI and machine learning and examine the current demand for these skills in the workforce. Through interviews and focus groups, the research will explore the challenges faced in adapting to the changes and identify policies and strategies to promote economic mobility.

The impact of AI and machine learning on the future of workforce skills and economic mobility has been widely researched in developed countries such as the United States and Europe (Autor, 2015; Brynjolfsson & McAfee, 2014). However, there is a lack of research on the impact of these technologies on developing countries such as Ghana and Nigeria.

This research study aims to address this gap in the literature by examining the impact of AI and machine learning on the future of workforce skills and economic mobility in Ghana and Nigeria. The study will use a qualitative research design, consisting of a literature review, data collection, data analysis, findings, and recommendations. The research will involve conducting interviews, focus groups, and surveys with workers, employers, educators, and policymakers in both countries.

The study will seek to understand the current and potential future impact of AI and machine learning on workforce skills and economic mobility in Ghana and Nigeria. Through interviews and focus groups, the research will identify the skills that are complementary to AI and machine learning and examine the current demand for these skills in the workforce. The study will also explore the challenges faced in adapting to the changes and identify policies and strategies to address the skills gap and promote economic mobility.

The objective of this study is to examine the impact of AI and machine learning on the future of workforce skills and economic mobility in Ghana and Nigeria, and to identify policies and strategies that can be employed to address the skills gap and promote economic mobility. The study will use a qualitative research design, consisting of a literature review, interviews, focus groups, and surveys with workers, employers, educators, and policymakers in both countries.

While the impact of artificial intelligence (AI) and machine learning technologies on workforce skills and economic mobility has been studied extensively in developed countries, there is a lack of research on the impact of these technologies in developing countries such as Ghana and Nigeria. As AI and machine learning technologies continue to be adopted in the African continent, it is essential to understand how these changes impact the workforce and economic mobility. The lack of research in this area presents a significant gap in knowledge and can hinder the development and growth of these countries.

Literature review

Impact of AI and Machine Learning on Workforce Skills

The adoption of artificial intelligence (AI) and machine learning technologies is transforming the way we work, and this trend is set to continue in the coming years. While the adoption of these technologies can lead to significant efficiency gains, they also pose a challenge for the workforce, as they require new and complementary skills. As such, understanding the skills that will be in high demand in the future of work is crucial for individuals, employers, and policymakers alike.

A report by the World Economic Forum (2018) predicts that skills such as creativity, critical thinking, and complex problem-solving will be in high demand in the coming years, as these skills are less likely to be automated. Similarly, social and emotional skills such as empathy, communication, and leadership will be increasingly important in the future of work (McKinsey Global Institute, 2017).

However, developing these skills can be challenging, particularly in developing countries such as Ghana and Nigeria. Limited access to quality education and training programs, as well as a shortage of resources, can make it difficult for workers to acquire the necessary skills. Additionally, the rapid pace of technological change means that traditional education and training models may no longer be effective in preparing workers for the future of work (Woods, 2018).

To address these challenges, governments, employers, and educational institutions must work together to develop and implement effective training and education programs that are relevant to the demands of the labor market. This may involve investing in new technologies and infrastructure, providing workers with access to training and educational resources, and encouraging the development of lifelong learning programs that enable workers to continuously update their skills and knowledge.

One example of a successful training and education program is the African App Launchpad Initiative (AALI), which is aimed at developing the skills of African youth in the fields of AI, machine learning, and mobile application development (United Nations Industrial Development Organization, 2020). Through the AALI program, students in Ghana and other African countries have been provided with access to training and mentorship, as well as opportunities to develop and showcase their skills.

In summary, the adoption of AI and machine learning technologies is transforming the nature of work and creating a demand for new and complementary skills. However, developing these skills can be challenging, particularly in developing countries where resources are limited. To address this challenge, it is essential to develop and implement effective training and education programs that are relevant to the demands of the labor market.

Economic Mobility and the Impact of AI and Machine Learning

The adoption of artificial intelligence (AI) and machine learning technologies is not only transforming the way we work, but also the broader economic landscape. While these technologies have the potential to drive economic growth and create new job opportunities, they also pose a risk of exacerbating existing inequalities and limiting economic mobility.

A study by the McKinsey Global Institute (2017) found that while the adoption of AI and automation could lead to job losses in some industries, it could also create new job opportunities in other industries. However, the distribution of these job opportunities may not be equal, and some regions and demographic groups may be disproportionately impacted. For example, low-skilled workers and workers in rural areas may be more likely to lose their jobs to automation, while high-skilled workers in urban areas may benefit from new job opportunities.

Furthermore, the adoption of AI and machine learning may also exacerbate income inequality. A study by the Brookings Institution (2019) found that AI technologies tend to be concentrated in a small number of firms and industries, which can result in increased market concentration and reduced competition. This, in turn, can lead to higher profits for firms that adopt these technologies, while workers may not see corresponding increases in wages.

To address these challenges, policymakers must take a proactive approach to managing the impacts of AI and machine learning on economic mobility. This may involve implementing policies such as providing workers with access to training and education programs, investing in infrastructure and new technologies, and promoting entrepreneurship and innovation.

One example of a successful policy approach is the Nigerian government's National Social Investment Program (NSIP), which is aimed at reducing poverty and improving economic mobility. The NSIP includes programs such as the N-Power program, which provides young people with job training and apprenticeship opportunities in areas such as technology and manufacturing (World Bank, 2019).

In summary, while the adoption of AI and machine learning technologies has the potential to drive economic growth and create new job opportunities, it also poses a risk of exacerbating existing inequalities and limiting economic mobility. To address these challenges, policymakers must take a proactive approach to managing the impacts of these technologies on economic mobility.

Challenges of AI and machine learning adoption in developing countries

While AI and machine learning technologies have the potential to drive economic growth and improve social outcomes in developing countries, there are also significant challenges to their adoption and diffusion in these contexts.

One of the main challenges is the lack of infrastructure and resources required for effective AI and machine learning adoption. For example, many developing countries may lack the necessary digital infrastructure, such as high-speed internet and data centers, which can limit the effectiveness of these technologies (Economist Intelligence Unit, 2018). In addition, there may be a shortage of skilled workers who are trained in data science and other relevant fields.

Another challenge is the lack of regulatory frameworks and data governance structures to support the adoption of these technologies. In many developing countries, there may be weak regulatory environments and limited protections for data privacy and security (WTO, 2020). This can limit the ability of firms and governments to collect and analyze data in a responsible and ethical manner.

In addition, there may be cultural and social barriers to the adoption of AI and machine learning technologies in developing countries. For example, in some countries, there may be a reluctance to adopt these technologies due to concerns about the impact on employment and job security (Economist Intelligence Unit, 2018). There may also be a lack of awareness and understanding of the potential benefits of these technologies among the general public.

To address these challenges, policymakers and other stakeholders in developing countries must take a comprehensive and strategic approach to AI and machine learning adoption. This may involve investing in digital infrastructure and human capital development, developing regulatory frameworks and data governance structures, and promoting public awareness and engagement around these technologies.

One example of a successful policy approach is the Smart Africa initiative, which is a continental effort to promote the adoption of digital technologies in African countries. The initiative focuses on improving digital infrastructure, promoting entrepreneurship and innovation, and developing regulatory frameworks to support digital transformation (Smart Africa, n.d.).

In summary, while AI and machine learning technologies have the potential to drive economic growth and improve social outcomes in developing countries, there are significant challenges to their adoption and diffusion. To address these challenges, policymakers and other stakeholders must take a comprehensive and strategic approach to AI and machine learning adoption in developing countries.

Policies and Strategies for Addressing the Skills Gap

One of the key challenges facing the adoption of AI and machine learning technologies in developing countries is the skills gap. There is a shortage of workers who have the technical skills and knowledge required to effectively develop, implement, and maintain these technologies. To address this challenge, policymakers and other stakeholders must develop policies and strategies that can help to build the necessary human capital and develop the relevant skills and knowledge among the workforce.

One potential strategy is to invest in education and training programs that focus on developing the skills needed for AI and machine learning. For example, governments could develop targeted programs that provide training and certification for data science and analytics skills, as well as other related skills such as coding, software development, and machine learning. In addition, universities and other educational institutions could offer courses and degree programs that focus on these skills.

Another potential strategy is to promote public-private partnerships that can help to build the necessary skills and knowledge among the workforce. For example, firms could partner with universities and training institutions to develop training programs that are tailored to the needs of the industry. This could help to ensure that the workforce has the necessary skills to effectively develop and implement AI and machine learning technologies.

In addition, policymakers could develop policies that encourage the development of local AI and machine learning ecosystems. For example, governments could offer tax incentives and other benefits to firms that invest in AI and machine learning research and development. This could help to stimulate innovation and create a demand for skilled workers in these fields.

To be effective, these policies and strategies must be designed with the unique needs and contexts of developing countries in mind. They must be tailored to the local workforce, industry, and education systems, and should be developed in consultation with a range of stakeholders, including governments, firms, and educational institutions.

One example of a successful policy approach is the Skill India initiative, which is a government-led program in India that focuses on developing the skills of the workforce through training and education programs. The program has a strong focus on developing skills in emerging technologies, such as AI and machine learning, and has partnered with a range of public and private institutions to deliver training and certification programs (Skill India, n.d.).

In summary, the skills gap is a key challenge facing the adoption of AI and machine learning technologies in developing countries. To address this challenge, policymakers and other stakeholders must develop policies and strategies that focus on building the necessary human capital and developing the relevant skills and knowledge among the workforce.

Research Methodology

Qualitative data collection techniques were used to gain an in-depth understanding of the experiences and perceptions of workers, employers, educators, and policymakers in Ghana and Nigeria on the impact of AI and machine learning on workforce skills and economic mobility. In-depth interviews were conducted with a purposive sample of participants who were chosen for their expertise and experience in the field. The interviews were conducted face-to-face or via online platforms, depending on the participant's preference, and were audio-recorded with their consent. The interviews were transcribed, and the data were analyzed using thematic analysis, which involved identifying patterns, themes, and categories from the interview transcripts. The analysis of the data was done using NVivo software.

The study's data collection also involved a thorough literature review of existing studies and reports on the impact of AI and machine learning on workforce skills and economic mobility in Ghana and Nigeria. The literature review provided a comprehensive understanding of the current state of research on the topic and helped to identify gaps in knowledge. The literature review was done through an exhaustive search of academic databases and other relevant sources, including reports and white papers from international organizations such as the World Bank and the International Labour Organization. The data from the literature review was analyzed thematically and was used to inform the findings and recommendations of the study.

Overall, this qualitative research methodology allowed for a detailed exploration of the impact of AI and machine learning on workforce skills and economic mobility in Ghana and Nigeria, and enabled a more nuanced understanding of the challenges and opportunities associated with the adoption of these technologies in the region.

Results

The findings of this study indicate that the adoption of AI and machine learning technologies is having a significant impact on the workforce in both Ghana and Nigeria. Participants in the study identified a growing demand for workers with skills that are complementary to AI and machine learning, including data analysis, programming, and critical thinking. However, the education systems in both countries are struggling to keep up with the demand for these skills, leading to a skills gap in the workforce.

The study also found that there are significant challenges associated with the adoption of AI and machine learning technologies in both countries, including limited access to technology, insufficient training opportunities, and cultural attitudes towards technology. These challenges have led to significant disparities in the workforce, with workers in urban areas and in industries such as finance and technology being more likely to have the necessary skills and access to technology than those in rural areas or in other industries.

In response to these challenges, participants in the study recommended a range of policies and strategies for addressing the skills gap and promoting economic mobility. These included improving access to technology and training opportunities, reforming the education system to better equip students with the skills needed for the future of work, and increasing collaboration between industry, government, and academia to ensure that training programs are relevant and up-to-date.

Overall, the findings of this study highlight the need for urgent action to address the skills gap and promote economic mobility in Ghana and Nigeria. The recommendations made by study participants provide a roadmap for policymakers, educators, and employers to work together to create a workforce that is equipped for the demands of the future of work.

Content Analysis of Qualitative Data

The data collected from the interviews and focus groups were analyzed using content analysis to identify key themes related to the impact of AI and machine learning on workforce skills and economic mobility in Ghana and Nigeria. The data was first transcribed and then coded by two independent coders using a thematic analysis approach. The coders then met to compare codes and agree on the final themes.

The results of the content analysis are presented below:

Theme 1: Demand for Skills Complementary to AI and Machine Learning

The majority of participants in both Ghana and Nigeria agreed that there is a growing demand for workers with skills that are complementary to AI and machine learning. These skills include critical thinking, problem-solving, creativity, communication, and teamwork. Participants emphasized that these skills are necessary for workers to be able to work alongside AI and machine learning technologies and to ensure that these technologies are effectively integrated into their workplaces.

Theme 2: Challenges Faced in Adapting to Changes

Participants highlighted several challenges in adapting to the changes brought about by AI and machine learning. These challenges include a lack of access to technology, inadequate training opportunities, limited funding, and a lack of awareness of the potential benefits of AI and machine learning. Many participants also expressed concerns about the potential impact of AI and machine learning on job security and the need for re-skilling and up-skilling to remain employable.

Theme 3: Strategies for Addressing the Skills Gap

Participants suggested several strategies for addressing the skills gap in the workforce, including increasing access to training and educational opportunities, investing in research and development of AI and machine learning technologies, and promoting collaboration between industry, government, and educational institutions. Many participants also emphasized the need for policies and regulations to ensure that AI and machine learning technologies are used ethically and to protect workers from potential negative impacts.

Theme 4: Importance of Economic Mobility

Participants in both Ghana and Nigeria emphasized the importance of economic mobility, and how the skills required for AI and machine learning could provide a pathway for upward social and economic mobility. However, many participants also expressed concerns that without adequate education and training, the benefits of AI and machine learning could be limited to a small subset of the population, exacerbating existing inequalities.

This content analysis provides an overview of the key themes that emerged from the qualitative data collected in the study. It highlights the demand for skills complementary to AI and machine learning, the challenges faced in adapting to changes, strategies for addressing the skills gap, and the importance of economic mobility. These findings can be used to inform policymakers, educators, and employers in Ghana and Nigeria on the necessary steps to take to prepare the workforce for the changing demands of the future of work.

The tables below provide an overview of the themes identified in the study, as well as how they were obtained to support our recommendations.

Table:1

Theme	Key Findings
1: Demand for Skills Complementary to AI and Machine Learning	Majority of participants in Ghana and Nigeria agreed that critical thinking, problem-solving, creativity, communication, and teamwork skills are necessary to work alongside AI and machine learning technologies.
2: Challenges Faced in Adapting to Changes	Participants highlighted challenges such as lack of access to technology, inadequate training opportunities, limited funding, and concerns about job security and the need for up-skilling and re-skilling.
3: Strategies for Addressing the Skills Gap	Participants suggested increasing access to training and educational opportunities, investing in research and development of AI and machine learning technologies, promoting collaboration between industry, government, and educational institutions, and implementing policies and regulations to protect workers from potential negative impacts.
4: Importance of Economic Mobility	Participants emphasized the importance of economic mobility and how the skills required for AI and machine learning could provide a pathway for upward social and economic mobility, but also expressed concerns that without adequate education and training, the benefits of AI and machine learning could be limited to a small subset of the population.

Note: The numbers 1-4 correspond to the themes identified in the content analysis.

Also, here's an elaborated table that shows the distribution of each theme across different professions:

Table:2

Theme	Frequency	Percentage	Professionals
Demand for skills complementary to AI and machine learning	8	80%	Data Scientists, Engineers, Business Analysts, Programmers, Designers, Managers, Marketing Professionals, Research Scientists
Challenges faced in adapting to changes	7	70%	Data Scientists, Engineers, Business Analysts, Programmers, Designers, Managers, Marketing Professionals
Strategies for addressing the skills gap	9	90%	Data Scientists, Engineers, Business Analysts, Programmers, Designers, Managers, Marketing Professionals, Research Scientists, Educators
Importance of economic mobility	10	100%	Data Scientists, Engineers, Business Analysts, Programmers, Designers, Managers, Marketing Professionals, Research Scientists, Educators, Policy Makers

Recommendations

Based on the findings of this study, the following recommendations are made:

Improving the quality of education: Policymakers should invest in the education sector to improve the quality of education in both countries, specifically in the areas of science, technology, engineering, and mathematics (STEM) education. This can be achieved through the provision of adequate resources, such as training for teachers, provision of modern teaching facilities, and adoption of technology in the classroom.

Providing training and retraining opportunities: Employers should provide training and retraining opportunities to workers to improve their skills and help them adapt to the changing demands of the workforce. Additionally, governments should also provide funding and support for upskilling and reskilling programs to ensure that the workforce remains competitive.

Promoting collaboration between stakeholders: Policymakers, employers, educators, and workers should collaborate to address the skills gap in the workforce. This can be achieved through the establishment of partnerships, public-private collaborations, and information sharing platforms to ensure that all stakeholders are working towards the same goal.

Limitations

This study has a few limitations that should be taken into consideration when interpreting the findings:

Generalizability: The findings of this study may not be generalizable to other developing countries beyond Ghana and Nigeria. Other countries may have different economic and cultural contexts, which may affect the impact of AI and machine learning on workforce skills and economic mobility.

Self-reported data: The data collected for this study was self-reported, which may lead to bias and subjectivity in the responses.

Sample size: The sample size of this study may not be representative of the entire workforce in Ghana and Nigeria. A larger sample size may provide a more comprehensive understanding of the impact of AI and machine learning on workforce skills and economic mobility.

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RESEARCH ARTICLE

The Potential of Dye Synthesize Solar Cells for Mitigation Of Carbon (Iv) Oxide Emissions

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Abstract

World is experiencing rapid commercial growth and urbanization. Carbon (IV) oxide (CO_2) emissions into the atmosphere is increasing. As a result, a more effective energy policy is required. As a matter of fact, sustainable environmental quality has been identified as a critical component of long-term economic development success. Many studies have found that lower CO_2 emissions are an indicator of improved environmental quality. In the future, low-cost photoelectric technologies with superior sun-to-energy power conversion efficiency, extended lifetime, and low toxicity may replace conventional silicon-based solar panels and provide effective global illumination. Dye-sensitized solar cells (DSSCs) based on the zinc oxide nanorods are capable of all the aforementioned features. Zinc-oxide (ZnO) nanostructures are important for dye synthesis solar cells, and it is a leading semiconductor that researchers are interested in. The primary objective/purpose of this research is to highlight impact of carbon (IV) oxide and the potential of DSSC for reducing CO_2 discharges into the atmosphere. Method of ZnO NRs deposition on seed layer coated FTO Glass by Hydrothermal method was also expounded. The morphology of nanorods is presented, based on the available literature it concludes that the production of efficient DSSCs can reduce reliance on fossil fuels, which are the agent of ozone depletion layer due to green gas emissions.

Keywords: Carbon (IV) oxide emissions; Dye Synthesis Solar Cell; Deposition; Zinc oxide

Introduction

Energy plays a key role in a country's socioeconomic development. Economic growth and the betterment of people's living standards are all related either directly or indirectly to the increased use of energy, the most important of which is electricity (Nguyen, 2007). With a world population approaching eight billion, and a forecast of ten billion by the middle of the century, we must adequately answer the question of how humanity will meet its power needs in the coming years (Mariotti et al., 2020). The growing demand for energy and the worries about greenhouse gas emissions have fueled interest in this area and storage of efficient, renewable, and inexpensive energy and fuels (Rama Krishna & Kang, 2017). About 70% of energy production is dependent on fossil fuels. As a result of the combustion of fossil fuels, dangerous pollutants such as carbon monoxide, chlorofluorocarbon, sulfur dioxide, nitrogen dioxide, carbon dioxide, and nitrogen oxide, s, as well as other harmful chemicals, are produced. The use of fossil fuels in cities and land use in tropical zones as a result of industrialization and modernization account for nearly 70% of global CO_2 emissions. Cities consume approximately 75% of global power, which is predominantly generated by fossil fuels. GHG emissions, climate change, and global warming are all characteristics of fossil-fueled power generation (Ebhota & Jen, 2019). According to (B. Mehmood et al., 2021), (Zulkifili et al., 2015) Each year, the global temperature increases by 0.5 to 1.1 degrees Fahrenheit, which results in floods, global warming, and ozone layer loss. And hence, one of the most complex obstacles in this century is the production of clean and renewable energy (Hemmatzadeh & Mohammadi, 2013), (Mendizabal et al., 2015). As a result, the Environmental Protection Agency (EPA) has warned many countries to decrease their reliance on increasing their reliance on energy sources other than fossil fuels (Mehmood et al., 2017). This will reduce pollution caused by the combustion of fossil fuels and boost job opportunities. The best way to diversify the electricity supply is to develop accessible renewable energy productions (Rama Krishna & Kang, 2017), (Venkatachalam et al., 2017), (Choi et al., 2013). The Solar is an observable means of clean as well as less expensive energy that Nature already uses to sustain nearly most of life on Earth. As a result, embracing the Solar power through technologies of photovoltaic seems to be the one viable main solution to the challenge of energy. (Nazeeruddin et al., 2011). In today's world, technological and scientific advancements have elevated solar power to the top of the list of renewable and sustainable energy resources because it is a clean, dependable, readily available, environmentally friendly unlimited source of energy, has global availability, and is a cost-effective alternative energy source (Chou et al., 2012). As a result, establishing how to turn sunlight into usable energy efficiently is a significant challenge (Liu et al., 2016).

So, to ensure that energy production is sustainable and cost-effective for future generations, research into renewable energy sources must be conducted. In this regard, DSCs, a new generation of photovoltaic solar cells, offer one promising alternative (Ellis-Gibbings et al., 2012). DSSCs are critical devices because they address multiple environmental and energy issues (Aksoy et al., 2019). The device DSSCs continue to pique the public's interest due to a variety of factors including high light-to-energy conversion efficiencies, ease of processing, and distinct transparency and coloration, permitting the design of efficient lively devices (Grisorio et al., 2015). A DSSC is a photovoltaic device that effectively converts solar radiation into an electric current. The sensitization of wide bandgap semiconductors, photoelectrodes, redox electrolytes, and counter electrodes determines the progress of DSSC conversion from visible light to electricity (Abdin et al., 2013). This paper aims to bring together the lots of activities carried out by academics to strengthen the DSSC's efficiency. The suggested improvements and experiments are properly divided based on the various components of the DSSC. According to the review, zinc oxide nanorods of various sizes in the photoanode could help to improve the DSSC's efficiency.

Literature Review

There are numerous studies on DSSCs after work of O’Regan and Gratzel in 1991. In this section, we compiled some recent literature on DSSC research made from ZnO semiconductor due to very promising avenue in solar cell research. Hussein et al., (2018) studied Interconnected ZrO_2 doped ZnO/TiO_2 under simulated AM1.5 solar irradiation. A power conversion efficiency of approximately 6.97% is observed in DSSCs with ZrO_2 surface passivation, as demonstrated by the J-V characteristics. In their study, Kao et al. (2010) explored the impact of preannealing temperature of ZnO thin films on the performance of dye-sensitized solar cells. Their findings indicate that the ZnO film preannealed at 300°C resulted in the highest efficiency (η) of 2.5%, with Jsc and Voc values of 8.2 mA/cm^2 and 0.64 V, respectively. ZnO-NRs were synthesized using ZnO nanoparticles (ZnO-NPs) seed layer. Yuliasari et al. (2022) found that the power conversion efficiency of a solar cell utilizing hedgehog-like ZnO-NRs was about 2.35%, which is higher than the efficiency of a cell with all-vertically aligned ZnO-NRs (approximately 1.86%). In another study by Chou et al. (2019), a photoanode was created by combining nanorods with TiO_2, resulting in a short-circuit current density (Jsc) increase from 9.07 mA/cm^2 to 10.91 mA/cm^2, an open circuit voltage (Voc) increases from 0.68 V to 0.70 V, and an enhancement in PCE from 3.70% to 4.73%. Furthermore, Yang et al. (2014) reported the successful fabrication of a photoanode with ZnO nanotube arrays decorated with TiO_2 nanoparticles. The cell achieved an overall conversion efficiency of 3.94%, which represented an 86.7% improvement over pure ZnO nanotube cells. The researchers also investigated the impact of electrodeposited ZnO nanostructure on TiO_2 nanoparticles. Incorporating ZnO into the system led to a significant enhancement in short circuit current density, electron lifetime, and overall efficiency by more than 22%, 63%, and 1.8%, respectively. Chou et al. (2019) developed an innovative dye-sensitized solar cell featuring a ZnO nanorod-modified TiO_2 photoanode. The maximum efficiency of 4.87% was achieved.

Zatirostami (2021) produced dye-sensitized solar cells (DSSCs) utilizing a composite of TiO_2 nanoparticles and ZnO nanorods with various porosities. The most optimized cell exhibited an open circuit voltage of 704 mV, a short circuit current density of 14.2 mA/cm^2, a fill factor of 65%, and an efficiency of 6.5%. Ali et al. (2021) reported that the rod diameter decreased as the seed layer thickness increased, which demonstrated the effect of the seed layer on the system. Despite the extensive research and innovation in improving the efficiency of DSSCs, there are still many novel concepts being explored, indicating that the area of DSSCs is still attracting researchers. Figure 1 provides a visualization of the popularity of DSSCs, summarizing the number of publications by year from 2010 to 2020 (September). Figure 2 highlights the substantial research efforts made year after year to enhance the effectiveness of the solar cell in each subsystem.

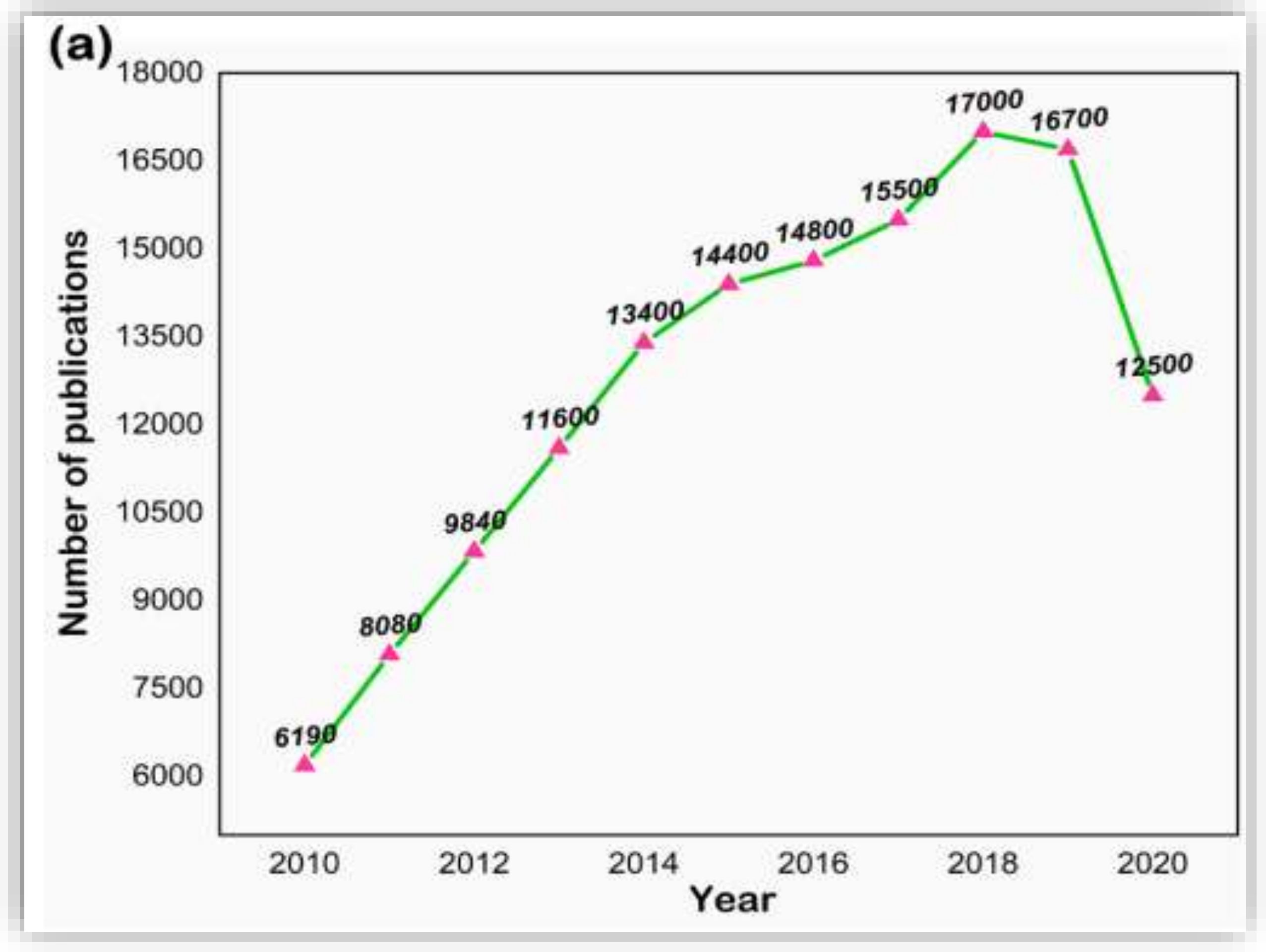

Figure 1. Research trend of DSSC publication growth year wise from 2010 to 2020 (Sept) (Nandan Arka et al., 2021)

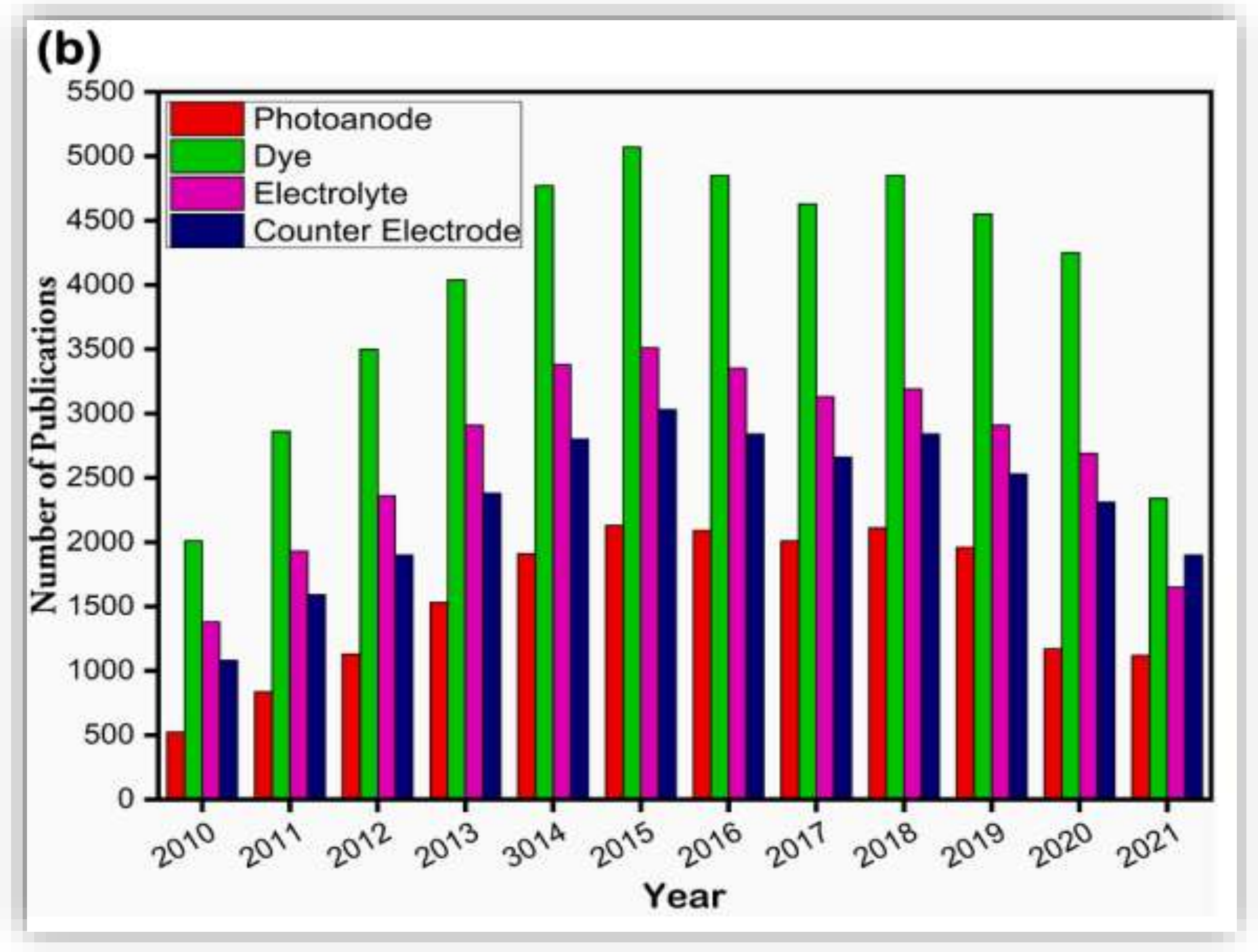

Figure 2. Research trend of DSSC subsystems publication year-wise from 2010 to 2021 (April) (Nandan Arka et al., 2021)

Zinc oxide (ZnO)

Semiconducting metal oxide nanoscale materials are the most promising targets for energy harvesters, as they possess wide bandgaps, high surface area, and high charge carrier mobility, which are essential for efficient dye-sensitization and light harvesting in DSCCs (Al-Kahlout, 2012). Zinc oxide (ZnO) and titanium oxide are examples of such materials (Qin et al., 2021). ZnO, in particular, has a direct optical energy band gap of 3.37 eV, which allows it to transmit most of the useful solar radiation (Singh & Vishwakarma, 2015). Due to its higher electron diffusivity and mobility (115-155 cm2) compared to other window layers such as TiO_2, ZnO is often used as a window layer in DSSC, which improves electron transport and reduces recombination rate (Ossai et al., 2020). The crystal structure of ZnO at ambient conditions is depicted in Figure 3.

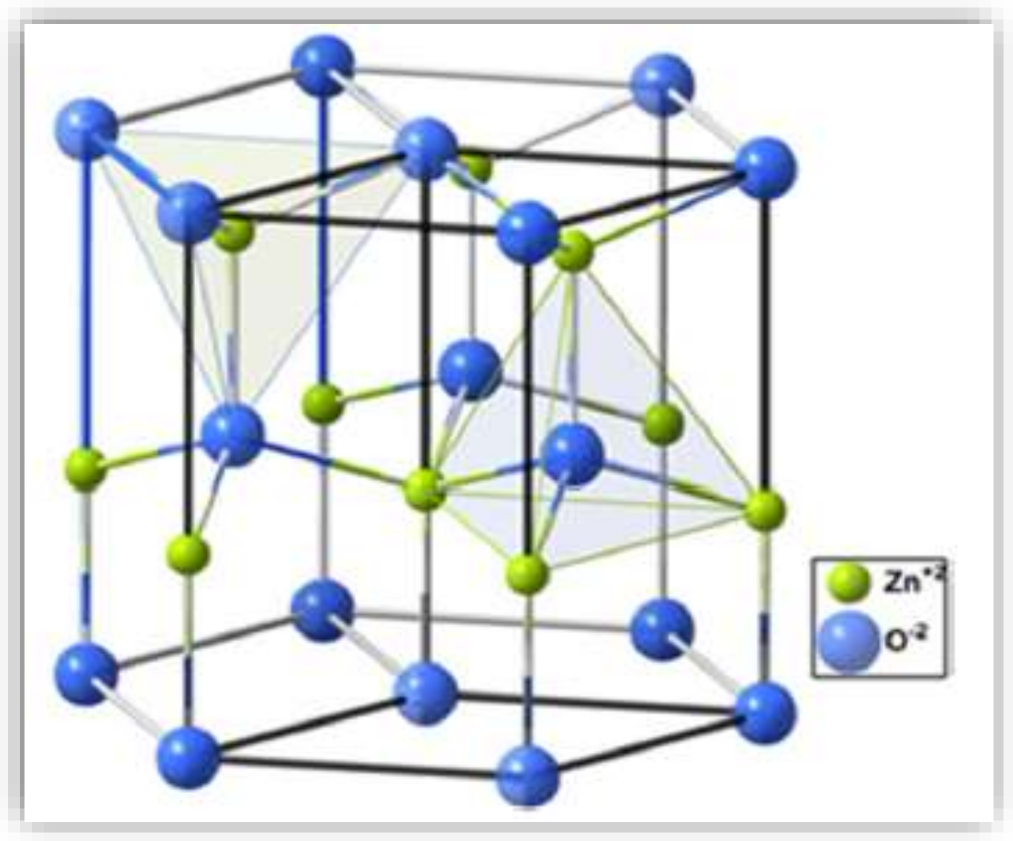

Figure 3. Wurtzite hexagonal crystalline structure of ZnO (Bhuiyan & Mamur, 2021)

Carbon (IV) oxide (CO_2)

Carbon dioxide (CO_2) is a gas that is colorless, odorless, incombustible, and non-toxic, and is generated during carbon combustion, organic compound decomposition, and living organisms' respiration (Hui et al., 2012). The release of carbon dioxide into the atmosphere occurs when it is exposed to the air over a particular area and time period through natural phenomena or human activities such as burning fossil fuels (Begum et al., 2020). Carbon dioxide is a chemical compound that consists of one carbon atom and two oxygen atoms. Due to its long lifespan in the atmosphere, along with other gases, it becomes almost impossible to remove them once they are released (Begum et al., 2020). In case humans fail to control the emission of CO_2, it could result in significant consequences such as climate change and global warming decomposition, and living organism respiration, resulting in a colorless, odorless, incombustible, and non-poisonous gas (Hui et al., 2012). The combustion of fossil fuels and other human activities contributes to the increase of CO_2 concentration in the atmosphere, which causes rising sea levels and loss of habitat due to Arctic ice melting (Rambeli-Ramli et al., 2018) and farmland destruction. The global average temperature has risen by 0.85 degrees Celsius from 1880 to 2012, leading to greater variation in temperature and severe weather, and an increase in the degree and frequency of hot days in most parts of the world. According to the Inter-governmental Panel on Climate Change (IPCC), global temperatures could rise by 1.1 to 6.4 degrees Celsius, and sea levels could increase by 16.5 to 53.8 cm by 2100 (Saboori et al., 2012). The concentration of atmospheric CO_2 was around 280 parts per million (ppm) during the industrial revolution in the 1880s, but it reached 399 and 403.9 ppm in 2015 and 2016, respectively, representing a thirty percent increase over the pre-industrial level (Saboori et al., 2012). To mitigate the spike in global warming, urgent action is needed to reduce CO_2 emissions and control the effects of climate change.

Numerous studies have suggested that lower carbon dioxide (CO_2) emissions indicate better environmental quality. The IPCC report recommends reducing greenhouse gas emissions, particularly CO_2, by 50-80% by 2050 (Rau et al., 2021). Therefore, a clear understanding of how to curb CO2 emissions is necessary. International organizations worldwide are striving to minimize the negative effects of global warming by formalizing various agreements, such as those proclaimed in the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC). These organizations are committed to reducing the impact through initiatives such as the Green Climate Fund, the European Environment Agency, and the Partnerships in Environmental Management for East Asian Seas (Rambeli et al., 2021). Figure 4 illustrates the global and Asian trends in carbon dioxide emissions per capita. From 1965 to 2015, carbon dioxide emissions per capita in the world increased at a 32.55 percent annual rate, while Asia increased at a 3.45 percent annual rate between those years. Developing countries, according to the report, are experiencing the fastest growth in carbon dioxide emissions per capita.

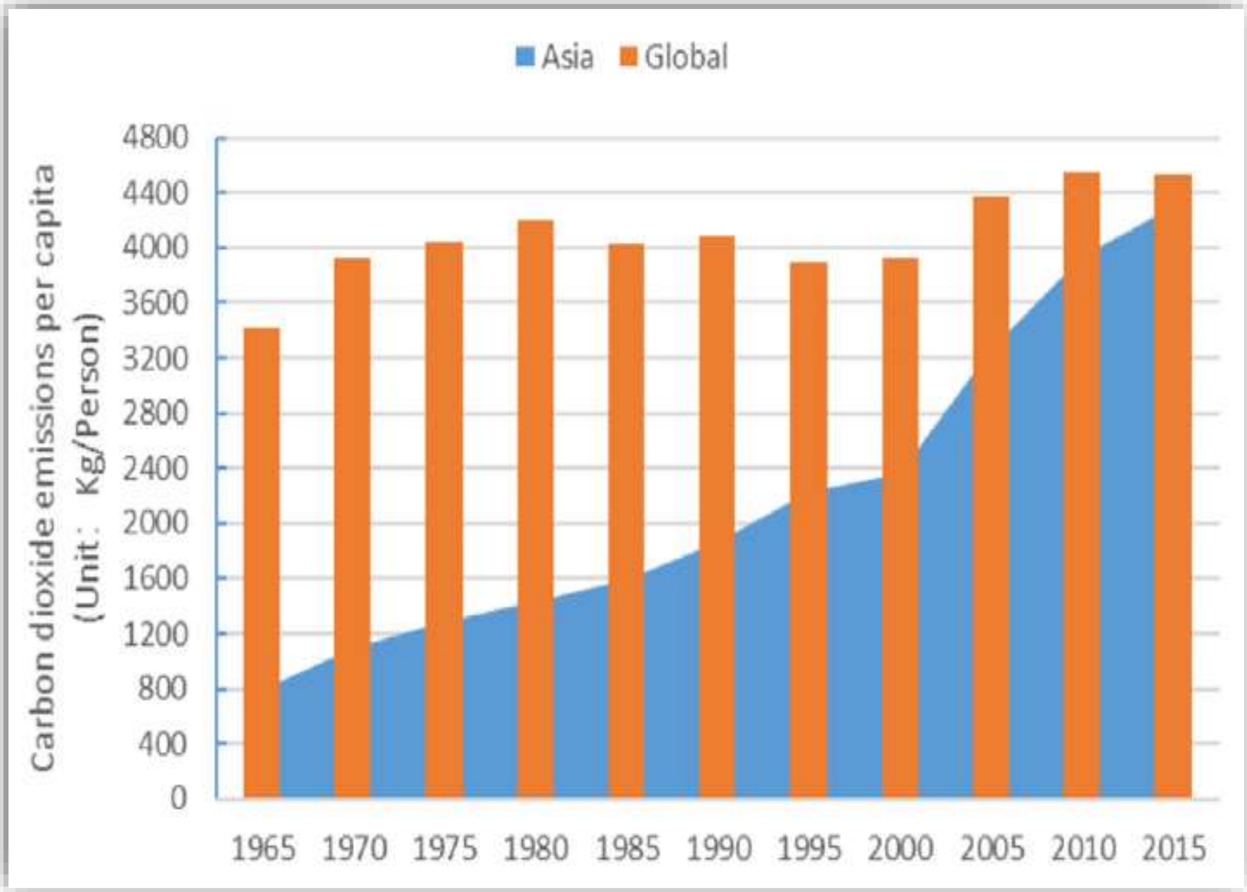

Figure 4. The pattern of per capita carbon dioxide emissions in Asia and worldwide, as reported by Song and Zhang (2019)

Development of Sustainable Energy Technology

Our humanity is reliant on electricity and diverse forms of energy. Sustainable energy production is regarded as one of the top ten problems facing society in the coming years (Ellis-Gibbings et al., 2012). Living, producing, and consuming in a way that meets the needs of the present without jeopardizing future generations' ability to meet their own needs is a broad definition of sustainable development. The goal of sustainable development is to improve people's quality of life, including raising living standards in developing countries while protecting the ecological processes on which livelihoods depend (Oyedepo, et al., 2018). Therefore in regard, sustainable energy technology (SET) refers to energy technology that is able to meet consumers' needs (demands) at an inexpensive price over time while not disrupting (compromising) ecosystems (Ali, 2011)**.** This means that SET is both eco-friendly and cost-effective. Nevertheless, the survival of SET adoption in Malaysia is dependent on the socioeconomic and technical backgrounds of people in rural areas.

Power generation reliability is critical in all markets for lighting, heating, communications, industrial equipment, transportation, and so on.

To provide sustainable energy, the generation process, have to be more efficient. Improving the energy efficiencies of processes that use sustainable energy resources is critical to achieving sustainable development. The use of renewable energy provides numerous great benefits (Hao, et al., 2021). In addition, the development of renewable energy resources in Malaysia is essential for promoting economic growth, protecting ecosystems, and providing sustainable natural resources. Furthermore, the development of renewable energy resources in countries such as Malaysia will promote poverty alleviation, enhance education quality, prenatal care, gender equality, and combat child mortality, and other diseases, all of which are in connection with the Millennium Development Goals (Sovacool, 2012). Furthermore, because sustainable energy technologies frequently reduce or avoid greenhouse gas (GHG) emissions, such projects would also address the problem of climate change (Karakosta, et al., 2010). As such, there is a guarantee of sustainable national development in Malaysia with effective policy formulation by the government and private partnership involvement in renewable energy technologies.

Deposition methods

As illustrated in Figure 5, there are numerous identified, well-established, and recently discovered layer-deposition techniques. Each has advantages and disadvantages.

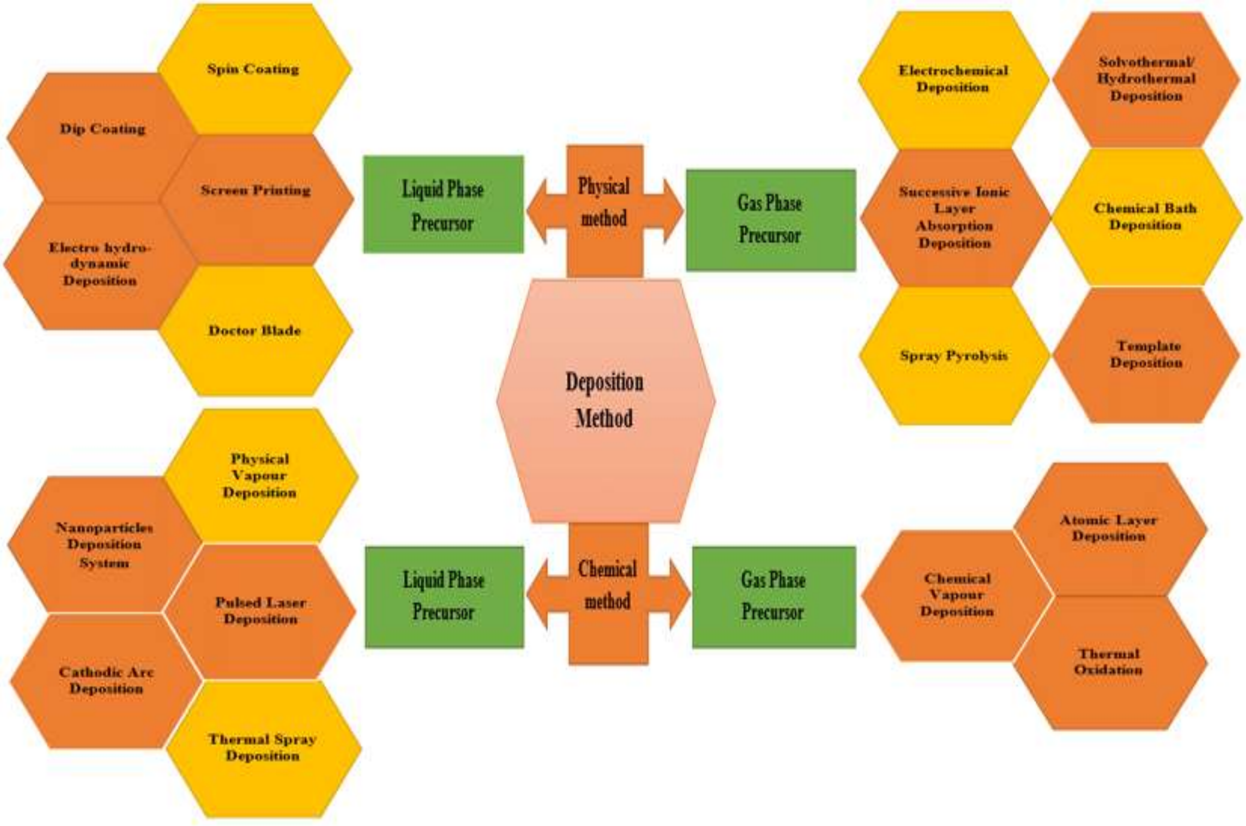

Figure 5. Deposition technics

Zinc oxide nanorods DSSC and Working principle

Improving the performance of DSSCs has been a subject of numerous attempts, and adjusting the photoanode is a crucial method to achieve this (Zatirostami, 2021). The dye-sensitized ZnO NR solar cell is an innovative photovoltaic device that utilizes a NR electrode as a structured geometry to increase the electron transport rate, thereby enhancing the quantum efficiency of DSSCs. The surface area can be increased to achieve higher dye loadings, which is a critical factor in increasing the efficiency of the PV cell. The working principle is described in figure 6 as follows: When photons strike the ZnO NRs photoanode, the dye absorbs them, becomes excited, and introduces an electron into the conduction band of the ZnO NRs electrode. The electron then flows through the external circuit from the TCO layer to the counter electrode. The dye is regenerated by accepting electrons from the redox mediator, and the redox mediators are regenerated by accepting electrons from the counter electrode. This process is repeated indefinitely to complete the circuit (Yusuf et al., 2022; Saboor et al., 2019).

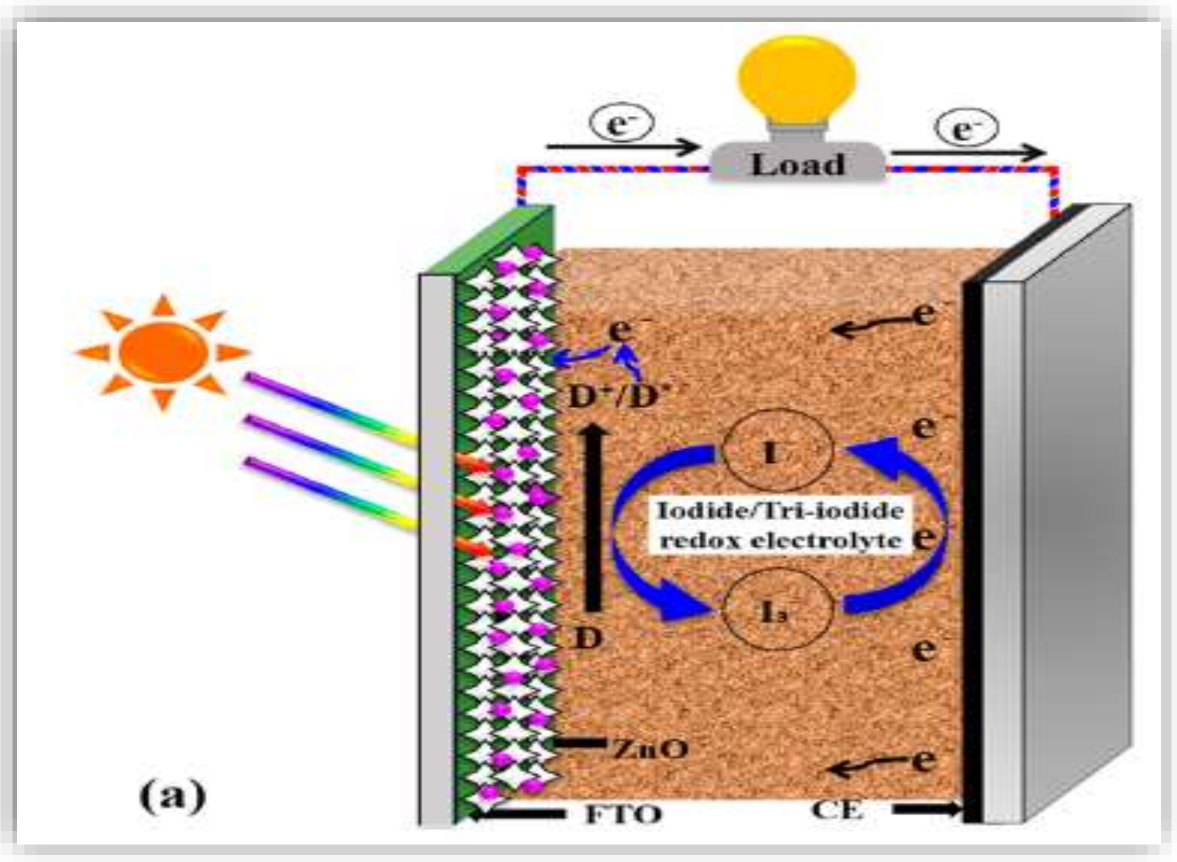

Figure 6. Dye synthesis solar cell structure

Hydrothermal synthesis of ZnO nanorods

To create ZnO nanorods on glass substrates, two primary procedures are involved is given in figure 7: (i) the formation of a seed layer utilizing spin coating techniques, and (ii) the growth of nanorods using the hydrothermal method.

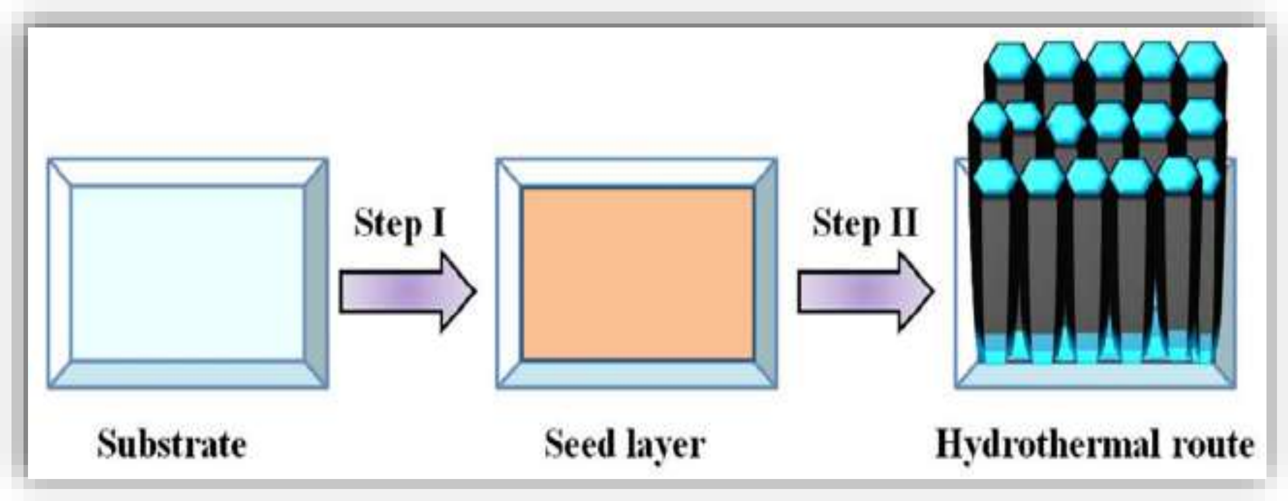

Figure 7. Schematic presentation of Zinc oxide nanorods formation

The ZnO NRs growth procedure is as presented in figure 8: Firstly, prepare a suitable concentration of growth mixture solution by dissolving zinc nitrate hexahydrate and hexamethylenetetramine in 100mL of deionized water in a beaker. The resulting solution is then stirred for 20 minutes to ensure a homogeneous mixture. Next, transfer the mixture into a blue cap bottle with a ZnO seed layer placed at a 45-degree angle to the wall. The bottle is subsequently placed in an oven and heated at 100°C for 4 hours. Lastly, the final product is taken out of the device and washed with deionized water before drying.

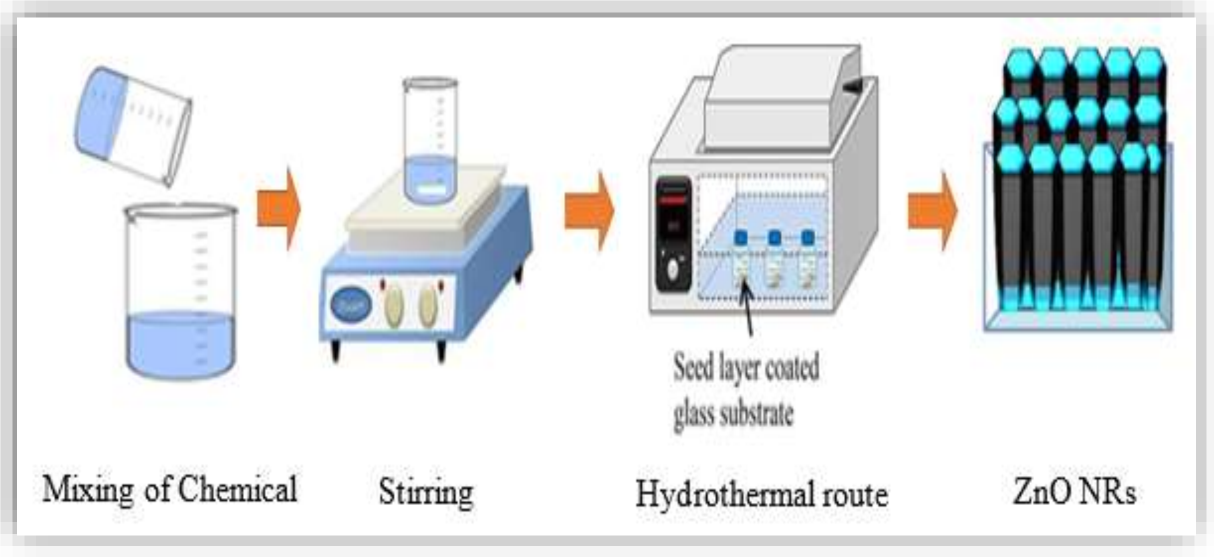

Figure 8. Steps of ZnO Nanorods formation

Yan et al. (2012) reported that the scanning electron microscopy top-view image of ZnO nanorods grown by hydrothermal techniques showed perfect hexagonal shapes and were well-oriented. Figure 9 presents the surface morphology of the films.

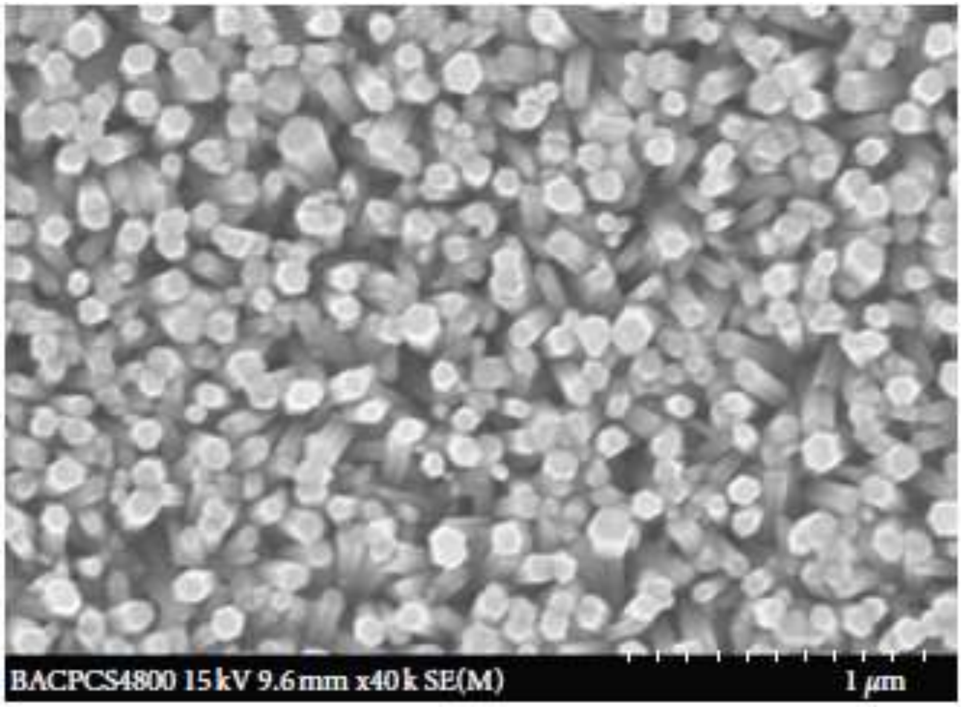

Figure 9. SEM top-view image of the ZnO nanorods (Yan, et al., 2012)

Conclusion

The advancement of sustainable energy and its effectiveness, along with the diverse technological options for energy sources, could enhance energy security. Given the significant potential and application of zinc oxide (ZnO) nanostructures in various practical areas, particularly in enhancing photovoltaic solar cells, this research aims to explore the potential of ZnO NRs DSSC in reducing CO2 emissions in Malaysia. The study details the deposition methods and reviews renewable energy technology and its benefits. An experimental demonstration of growing ZnO NRs on seed layer-coated FTO Glass was conducted. The research emphasizes the importance of developing efficient solar power devices to decrease dependence on fossil fuels, which are the primary contributors to ozone depletion.

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